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the Acid Deposition Research Program

BIOPHYSICAL RESEARCH

RESULTS OF THE EMISSION SOURCE SURVEYS: EMISSION INVENTORY OF SULPHUR OXIDES AND NITROGEN OXIDES IN ALBERTA

by:

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Bow Valley Resource Services Ltd.
Calgary, Alberta, Canada

November, 1987

PRIME RESEARCH CONTRACTOR:

The Kananaskis Centre for Environmental Research
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Calgary, Alberta, Canada

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Emission Inventory

Report Number	References
☐ ADRP-B-12-87	Picard, D. J., and Colley, D. G., and Boyd, D. H. 1987. **Overview of the Emission Data: Emission Inventory of Sulphur Oxides and Nitrogen Oxides in Alberta.** Prep for the Acid Deposition Research Program by Western Research, Division of Bow Valley Resource Services Ltd., Calgary, Alberta, Canada. ISBN 0-921625-18-9 (Volume 1) ISBN 0-921625-17-0 (Set of 4)
☐ ADRP-B-13-87	Picard, D. J., and Colley, D. G., and Boyd, D. H. 1987. ***Design of the Emission Inventory: Emission Inventory of Sulphur Oxides and Nitrogen Oxides in Alberta.** Prep for the Acid Deposition Research Program by Western Research, Division of Bow Valley Resource Services Ltd., Calgary, Alberta, Canada. ISBN 0-921625-19-7 (Volume 2) ISBN 0-921625-17-0 (Set of 4)
☐ ADRP-B-14-87	Picard, D. J., and Colley, D. G., and Boyd, D. H. 1987. ***Emission Data Base: Emission Inventory of Sulphur Oxides and Nitrogen Oxides in Alberta.** Prep for the Acid Deposition Research Program by Western Research, Division of Bow Valley Resource Services Ltd., Calgary, Alberta, Canada. ISBN 0-921625-20-0 (Volume 3) ISBN 0-921625-17-0 (Set of 4)
☐ ADRP-B-15-87	Picard, D. J., and Colley, D. G., and Boyd, D. H. 1987. ***Results of the Emission Source Surveys: Emission Inventory of Sulphur Oxides and Nitrogen Oxides in Alberta.** Prep for the Acid Deposition Research Program by Western Research, Division of Bow Valley Resource Services Ltd., Calgary, Alberta, Canada. ISBN 0-921625-21-9 (Volume 4) ISBN 0-921625-17-0 (Set of 4)

***Detailed data compilations, of technical interest.**

EMISSION INVENTORY OF SULPHUR OXIDES AND NITROGEN OXIDES IN ALBERTA

VOLUME 4
RESULTS OF THE EMISSION SOURCE SURVEYS

by

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EXECUTIVE SUMMARY

Air quality predictions play an important role in solving existing air pollution problems and in evaluating the potential impact of proposed emission sources. To predict air quality properly at a given location, it is necessary to identify all emission sources that will have significant impact at that location. Furthermore, the atmospheric pollutants that are emitted by these sources must be identified and quantitatively characterized. Once the air quality predictions have been made, it is desirable to have some historical air quality data for comparison. An efficient means of obtaining this information is through the use of detailed emission inventories and an inventory of air quality monitoring stations.

With specific regard to acid-forming emissions (i.e., sulphur dioxide and nitrogen oxides), it has been recognized that existing inventories for Alberta are either incomplete or do not provide sufficient detail to permit the investigation of specific regions within the province. Therefore, as part of the Alberta Government/Industry Acid Deposition Research Program (ADRP), three comprehensive inventories have been developed, namely:

- a sulphur dioxide (SO_2) emission inventory,
- a nitrogen oxides (NO_x) emission inventory, and
- an inventory of air quality monitoring stations.

The basic objectives in developing these three inventories have been:

(1) To identify all noteworthy anthropogenic sources of SO_2 and NO_x emissions in Alberta. This includes all SO_2 and NO_x emission sources that are licensed by the Alberta Government to operate under the Clean Air Act, sour oil batteries that emit more than 0.2 tonnes/day (t/d) of SO_2, and the following NO_x emission sources:

- industrial engines with a maximum rated power output of greater than 100 kW,
- urban centres, and
- the major portions of high traffic highways in the province (Highways 1, 2 and 16).

Licensed industrial sources include natural gas processing facilities, oil refineries, oil sands and heavy oil recovery facilities, fertilizer and chemical plants, power generation plants, pulp and paper plants, and cement plants.

Sources were identified on the basis of 1985-86 records available from government agencies and existing inventories. Emissions were estimated based on 1984 production data. Limited verification and updating of sources occurred in 1987.

(2) To characterize each emission source, as appropriate, with respect to:

- type of emission (i.e., NO_x or SO_2),
- geographic location (i.e., Legal Subdivision, Section, Township, and Range),
- environmental setting (surrounding vegetation, ecoregion type),
- physical characteristics (e.g., stack height and diameter),
- maximum licensed emission rate (where applicable), and
- emission characteristics (i.e., exit velocity, exit temperature, average emission rate, temporal variations and emission rate precision).

(3) To conduct a limited NOx source sampling program in order to develop Alberta-specific NOx emission factors for natural gas fueled reciprocating and turbine engines, and to assess the importance of waste gas incinerator units as NOx emission sources.

(4) To identify all air quality monitoring stations at which ambient levels of NOx and/or SO_2 are measured.

(5) To computerize the inventories so that information may be easily retrieved and the inventories easily updated.

The three inventories are intended to serve as a source of information that will assist investigators in estimating the average rates of NOx and SO_2 emission in Alberta, and the distribution of these emissions by geographic area, industry type, and environmental setting (ecoregion). The inventories will also be useful in predicting changes in emission levels by the current emission sources due to future changes in production levels (i.e., forecasting future emissions). Administrative information, including operator name, approvals and regulatory information, is also provided for each industrial source to facilitate source-specific research.

To enable use of the emissions data base in emissions forecasting and to allow prediction of emission rates from sources for which actual emission data are unavailable, emission rates for each of the sources inventoried have been estimated based on the use of emission factors. Emission factors are average values that relate the emission of NOx or SO_2, as appropriate, to a suitable operating parameter of the sources (generally, process production data).

The estimated emission rates presented in the emissions data base are expressed as average daily values. As such, these emission rates have been averaged over the sum of both operating and non-operating periods (most emission sources experience some down time during the year, usually for maintenance purposes). Although estimates of typical emission rates during operating periods are not presented in the inventory, these values may be readily determined using available process production data and the presented emission factors.

The emissions data base comprises 565 sources of SO_2 emissions and 4025 sources of NO_x emissions. In total, 1945.2 t/d of SO_2 and NO_x emissions were inventoried, 1267.0 t/d of SO_2 and 678.2 t/d of NO_x. The petroleum industry is by far the major source, accounting for approximately 38 percent of NO_x emissions and 82 percent of SO_2 emissions. Other important sources are electric power plants (NO_x and SO_2 emissions), highways (NO_x emissions), and urban centres (NO_x emissions).

Overall, it was determined that the majority of the SO_2 and NO_x emissions (approximately 1398.0 t/d or 71.9 percent of the total) occur in the southern half of the province where industrial activity is greatest. Although numerous sources of these pollutants were identified, the total provincial emission of SO_2 and NO_x is dominated by a few large sources rather than many smaller sources. The ten highest emitters of SO_2 account for 61.2 percent of the total SO_2 emissions, and the ten highest emitters of NO_x account for 38.5 percent of the total NO_x emissions.

The developed inventories have been computerized using a microcomputer-based data management system. The system chosen for this purpose was dBase III, a popular and powerful industry-standard database package that is designed for IBM and compatible computers. To assist users who may not be familiar with dBase III, a special application program named AAESI (an acronym for Alberta Atmospheric Emission Source Inventories) has been developed.

In addition to development of the three inventories that comprised this study, there are a number of other projects that are being conducted as part of the ADRP. One of these projects is a comprehensive air quality monitoring (AQM) program, involving three AQM stations. One AQM station is for the measurement of "background" air quality of air entering Alberta and is situated in the Fortress Mountain ski area of the Kananaskis Valley in the Rocky Mountains, 70 km west of Calgary, Alberta. The remaining two AQM stations are located 40 km north of Calgary on agricultural land near Crossfield, Alberta. One of the AQM stations is located west of Crossfield to assess air quality after the air has entered the Province of Alberta and been altered by regional scale emissions. The second AQM station is located southeast of Crossfield and is influenced by emissons from many sources such as Highway 2, City of Calgary, City of Airdrie, Town of Crossfield, two mushroom factories, and several sour gas (extraction) plants. A detailed survey of the incinerator stack from the sour gas plant closest to the second AQM station was included as part of the source sampling survey program conducted.

Documentation of the developed inventories is presented in four volumes. Volume 1, Overview of the Emission Data, comprises a brief summary describing development of the inventory, a summary of emissions data by emission type, geographic region, industrial category and ecoregion, a comparison with results of previous inventories, and a summary of the air quality monitoring station inventory. Conclusions and recommendations are also presented in this volume. Detailed summary tables describing emissions by major source category, petroleum industry facility type, and source type for each geographic emission region are appended to the volume.

Volume 2, Design of the Emission Inventory, presents detailed information on the classification systems, source characterization, emission calculations, and data fields employed for each emission type. Details describing the source sampling program conducted as part of the NO_x inventory and the computerization of the inventories are also presented in this volume. Furthermore, a detailed discussion of some of the major air quality monitoring networks in Alberta is included.

Volume 3, Emission Data Base, is a complete printout of the three inventories.

Volume 4, Results of the Emission Source Surveys, presents detailed results of the surveys conducted as part of the emissions inventory.

This Executive Summary is common to all volumes.

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TABLE OF CONTENTS

VOLUME 4

PAGE

EXECUTIVE SUMMARY i
ACKNOWLEDGEMENTS vii
TABLE OF CONTENTS viii
LIST OF TABLES x

1. SOURCE TESTING AT A SOUR GAS (EXTRACTION) PLANT NEAR CROSSFIELD - SUMMARY REPORT 1

    1.1 Summary 1
    1.2 Introduction 1
    1.3 Procedure 2
    1.4 Results and Discussion 3
    1.5 Conclusions 6
    1.6 Computer Output 7

2. NO_x SOURCE SAMPLING PROGRAM 29

    2.1 Individual Reports of the Surveyed Reciprocating Engines 30

        2.1.1 Natural Gas Fueled Engines: NO_x Test Report No. R-1 31
        2.1.2 Natural Gas Fueled Engines: NO_x Test Report No. R-2 42
        2.1.3 Natural Gas Fueled Engines: NO_x Test Report No. R-3 50
        2.1.4 Natural Gas Fueled Engines: NO_x Test Report No. R-4 59
        2.1.5 Natural Gas Fueled Engines: NO_x Test Report No. R-5 68
        2.1.6 Natural Gas Fueled Engines: NO_x Test Report No. R-6 77
        2.1.7 Natural Gas Fueled Engines: NO_x Test Report No. R-7 85
        2.1.8 Natural Gas Fueled Engines: NO_x Test Report No. R-8 93
        2.1.9 Natural Gas Fueled Engines: NO_x Test Report No. R-9 101
        2.1.10 Natural Gas Fueled Engines: NO_x Test Report No. R-10 109
        2.1.11 Natural Gas Fueled Engines: NO_x Test Report No. R-11 117
        2.1.12 Natural Gas Fueled Engines: NO_x Test Report No. R-12 125

Table of Contents (continued)

PAGE

2.2 Detailed Reports of the Surveyed Turbine Engines ... 133

2.2.1 Natural Gas Fueled Engines: NO_x Test Report No. T-1 134
2.2.2 Natural Gas Fueled Engines: NO_x Test Report No. T-2 144
2.2.3 Natural Gas Fueled Engines: NO_x Test Report No. T-3 152
2.2.4 Natural Gas Fueled Engines: NO_x Test Report No. T-4 160
2.2.5 Natural Gas Fueled Engines: NO_x Test Report No. T-5 168
2.2.6 Natural Gas Fueled Engines: NO_x Test Report No. T-6 176

2.3 Detailed Reports of the Surveyed Waste Gas Incinerator Units 185

2.3.1 Incinerator Stacks: NO_x Test Report No. I-1 186
2.3.2 Incinerator Stacks: NO_x Test Report No. I-2 193
2.3.3 Incinerator Stacks: NO_x Test Report No. I-3 198

3. REFERENCES CITED 203

LIST OF TABLES

PAGE

1. Summary of Source Emission Test Results 4

2. Total Flue Gas Composition - Mole Percent 5

3. Flue Gas Composition: NO_x Test Report No. R-1 35

4. Fuel Gas Composition: NO_x Test Report No. R-1 36

5. NO_x Determination - Field Data: NO_x Test Report No. R-1 37

6. NO_x Determination - Lab Data: NO_x Test Report No. R-1 38

7. Overall Gas Compositions: NO_x Test Report No. R-1 .. 39

8. Flue Gas Composition: NO_x Test Report No. R-2 44

9. Fuel Gas Composition: NO_x Test Report No. R-2 45

10. NO_x Determination - Field Data: NO_x Test Report No. R-2 46

11. NO_x Determination - Lab Data: NO_x Test Report No. R-2 47

12. Overall Gas Compositions: NO_x Test Report No. R-2 .. 48

13. Flue Gas Composition: NO_x Test Report No. R-3 52

14. Fuel Gas Composition: NO_x Test Report No. R-3 53

15. NO_x Determination - Field Data: NO_x Test Report No. R-3 54

16. NO_x Determination - Lab Data: NO_x Test Report No. R-3 55

17. Overall Gas Compositions: NO_x Test Report No. R-3 .. 56

18. Flue Gas Composition: NO_x Test Report No. R-4 61

19. Fuel Gas Composition: NO_x Test Report No. R-4 62

20. NO_x Determination - Field Data: NO_x Test Report No. R-4 63

List of Tables (continued)

PAGE

21. NO_x Determination - Lab Data: NO_x Test Report No. R-4 64

22. Overall Gas Compositions: NO_x Test Report No. R-4 .. 65

23. Flue Gas Composition: NO_x Test Report No. R-5 70

24. Fuel Gas Composition: NO_x Test Report No. R-5 71

25. NO_x Determination - Field Data: NO_x Test Report No. R-5 72

26. NO_x Determination - Lab Data: NO_x Test Report No. R-5 73

27. Overall Gas Compositions: NO_x Test Report No. R-5 .. 74

28. Flue Gas Composition: NO_x Test Report No. R-6 79

29. Fuel Gas Composition: NO_x Test Report No. R-6 80

30. NO_x Determination - Field Data: NO_x Test Report No. R-6 81

31. NO_x Determination - Lab Data: NO_x Test Report No. R-6 82

32. Overall Gas Compositions: NO_x Test Report No. R-6 .. 83

33. Flue Gas Composition: NO_x Test Report No. R-7 87

34. Fuel Gas Composition: NO_x Test Report No. R-7 88

30. NO_x Determination - Field Data: NO_x Test Report No. R-6 81

31. NO_x Determination - Lab Data: NO_x Test Report No. R-6 82

32. Overall Gas Compositions: NO_x Test Report No. R-6 .. 83

33. Flue Gas Composition: NO_x Test Report No. R-7 87

34. Fuel Gas Composition: NO_x Test Report No. R-7 88

35. NO_x Determination - Field Data: NO_x Test Report No. R-7 89

List of Tables (continued)

PAGE

36. NO_x Determination - Lab Data: NO_x Test Report No. R-7 90

37. Overall Gas Compositions: NO_x Test Report No. R-7 .. 91

38. Flue Gas Composition: NO_x Test Report No. R-8 95

39. Fuel Gas Composition: NO_x Test Report No. R-8 96

40. NO_x Determination - Field Data: NO_x Test Report No. R-8 97

41. NO_x Determination - Lab Data: NO_x Test Report No. R-8 98

42. Overall Gas Compositions: NO_x Test Report No. R-8 .. 99

43. Flue Gas Composition: NO_x Test Report No. R-9 103

44. Fuel Gas Composition: NO_x Test Report No. R-9 104

45. NO_x Determination - Field Data: NO_x Test Report No. R-9 105

46. NO_x Determination - Lab Data: NO_x Test Report No. R-9 106

47. Overall Gas Compositions: NO_x Test Report No. R-9 .. 107

48. Flue Gas Composition: NO_x Test Report No. R-10 111

49. Fuel Gas Composition: NO_x Test Report No. R-10 112

50. NO_x Determination - Field Data: NO_x Test Report No. R-10 113

51. NO_x Determination - Lab Data: NO_x Test Report No. R-10 114

52. Overall Gas Compositions: NO_x Test Report No. R-10 . 115

53. Flue Gas Composition: NO_x Test Report No. R-11 119

54. Fuel Gas Composition: NO_x Test Report No. R-11 120

55. NO_x Determination - Field Data: NO_x Test Report No. R-11 121

List of Tables (continued)

PAGE

56. NO_x Determination - Lab Data: NO_x Test Report No. R-11 122

57. Overall Gas Compositions: NO_x Test Report No. R-11 . 123

58. Flue Gas Composition: NO_x Test Report No. R-12 127

59. Fuel Gas Composition: NO_x Test Report No. R-12 128

60. NO_x Determination - Field Data: NO_x Test Report No. R-12 129

61. NO_x Determination - Lab Data: NO_x Test Report No. R-12 130

62. Overall Gas Compositions: NO_x Test Report No. R-12 . 131

63. Flue Gas Composition: NO_x Test Report No. T-1 138

64. Fuel Gas Composition: NO_x Test Report No. T-1 139

65. NO_x Determination - Field Data: NO_x Test Report No. T-1 140

66. NO_x Determination - Lab Data: NO_x Test Report No. T-1 141

67. Overall Gas Compositions: NO_x Test Report No. T-1 .. 142

68. Flue Gas Composition: NO_x Test Report No. T-2 146

69. Fuel Gas Composition: NO_x Test Report No. T-2 147

70. NO_x Determination - Field Data: NO_x Test Report No. T-2 148

71. NO_x Determination - Lab Data: NO_x Test Report No. T-2 149

72. Overall Gas Compositions: NO_x Test Report No. T-2 .. 150

73. Flue Gas Composition: NO_x Test Report No. T-3 154

74. Fuel Gas Composition: NO_x Test Report No. T-3 155

75. NO_x Determination - Field Data: NO_x Test Report No. T-3 156

List of Tables (continued)

PAGE

76. NO_x Determination - Lab Data: NO_x Test Report No. T-3 157

77. Overall Gas Compositions: NO_x Test Report No. T-3 .. 158

78. Flue Gas Composition: NO_x Test Report No. T-4 162

79. Fuel Gas Composition: NO_x Test Report No. T-4 163

80. NO_x Determination - Field Data: NO_x Test Report No. T-4 164

81. NO_x Determination - Lab Data: NO_x Test Report No. T-4 165

82. Overall Gas Compositions: NO_x Test Report No. T-4 .. 166

83. Flue Gas Composition: NO_x Test Report No. T-5 170

84. Fuel Gas Composition: NO_x Test Report No. T-5 171

85. NO_x Determination - Field Data: NO_x Test Report No. T-5 172

86. NO_x Determination - Lab Data: NO_x Test Report No. T-5 173

87. Overall Gas Compositions: NO_x Test Report No. T-5 .. 174

88. Flue Gas Composition: NO_x Test Report No. T-6 178

89. Fuel Gas Composition: NO_x Test Report No. T-6 179

90. NO_x Determination - Field Data: NO_x Test Report No. T-6 180

91. NO_x Determination - Lab Data: NO_x Test Report No. T-6 181

92. Overall Gas Compositions: NO_x Test Report No. T-6 .. 182

93. NO_x Determination - Field Data NO_x Test Report No. I-1 190

94. NO_x Determination - Lab Data NO_x Test Report NO. I-1 190

95. SO_x Stack Survey Results: NO_x Test Report No. I-1 .. 191

List of Tables (continued)

PAGE

96. Summary of NO_x Emission Testing: NO_x Test Report No. I-1 192

97. NO_x Determination - Field Data NO_x Test Report No. I-2 195

98. NO_x Determination - Lab Data NO_x Test Report NO. I-2 195

99. SO_x Stack Survey Results: NO_x Test Report No. I-2 .. 196

100. Summary of NO_x Emission Testing: NO_x Test Report No. I-2 197

101. NO_x Determination - Field Data NO_x Test Report No. I-3 200

102. NO_x Determination - Lab Data NO_x Test Report NO. I-3 200

103. SO_x Stack Survey Results: NO_x Test Report No. I-3 .. 201

104. Summary of NO_x Emission Testing: NO_x Test Report No. I-3 202

1. SOURCE TESTING AT A SOUR GAS (EXTRACTION) PLANT NEAR CROSSFIELD - SUMMARY REPORT

Test Date:	August 21 to 22, 1985
Test Location:	NE 14-28-1 W5M (Crossfield Area)
Tested by:	R. Tamura & M. Towill

1.1 SUMMARY

Six stack surveys were conducted on the incinerator stack for the sulphur recovery unit at a Sour Gas (Extraction) Plant located near Crossfield. These tests were conducted over a two day period with three tests being performed each day.

During the test period plant operation was stable. As would be expected, results of the individual tests compared well with one another (i.e., generally within 10 percent). Sulphur oxides were the dominant pollutant emitted. The highest rate at which sulphur oxides were emitted was 50.534 t/d (expressed as an SO_2 equivalent). This is approximately 69 percent of the maximum value, 73.2 t/d, for which the plant is licensed to operate under the Clean Air Act.

Only small amounts of nitrogen oxides (NO_x) were emitted. The highest determined rate of NO_x emission was 0.096 t/d (expressed as an NO_2 equivalent).

1.2 INTRODUCTION

Under the auspices of the Alberta Government/Industry Acid Deposition Research Program (ADRP), three comprehensive inventories are being developed, namely,

- a sulphur dioxide (SO_2) emission inventory,
- a nitrogen oxides (NO_x) emission inventory, and
- an inventory of air quality monitoring stations.

In addition to development of the inventories, a number of other projects are being conducted as part of ADRP. One of these projects is a comprehensive air quality monitoring (AQM) program involving three AQM stations. One AQM station is for the measurement of "background" air quality of air entering Alberta and is situated in the Rocky Mountains at 2103 m in the Fortress Mountain ski area in the Kananaskis Valley, 70 km west of Calgary, Alberta. The remaining two AQM stations are located 40 km north of Calgary on agricultural land near Crossfield, Alberta. One of the AQM stations is located west of Crossfield and is described as a "regional" location to assess air quality after the air has entered the Province of Alberta and been altered by regional scale emissions. The second AQM station is located southeast of Crossfield and is influenced by emissions from many sources such as Highway 2, City of Calgary, City of Airdrie, Town of Crossfield, two mushroom factories, and several sour gas (extraction) plants. Six stack surveys were conducted on the incinerator stack at the gas plant closest to the second AQM station. This testing was conducted during the period August 21 to 22, 1985.

1.3 PROCEDURE

The six stack surveys were conducted over a two day period, during which the plant was under normal load and stable operation. Each survey consisted of:

- determination of stack gas velocity and volumetric flow rate,
- determination of gas composition and molecular weight,
- determination of moisture content,
- determination of SO_x, and
- determination of NO_x.

Each of these determinations, with the exception of that for SO_x, was conducted in accordance with the Alberta Stack Sampling Code (Alberta Environment 1976).

SO_x emissions (i.e., the sum of SO_2 and SO_3 emissions) were determined using a modification of Alberta Environment (AE) (1976)Method 5 for determination of SO_2 emissions. AE Method 5 requires that a distinction be made between SO_2 and SO_3 emissions. This is achieved through the use of two quantitative absorption processes - first the sample is reacted with isopropanol for preferential removal of the SO_3 and then it is reacted with an aqueous H_2O_2 solution for removal of the SO_2. Since a distinction between SO_2 and SO_3 emission is not required here, the isopropanol solution was omitted and the SO_2 and SO_3 reacted simultaneously using the H_2O_2 solution to obtain total SO_x. The result of the modification is a simplified method for determination of SO_x emissions. This modified method is accepted by Alberta Environment for use in routine compliance tests.

1.4 RESULTS AND DISCUSSION

Computer output for the specified determinations are appended in Section 1.6. A summary of these results is presented in Table 1. Overall flue gas composition during each test is presented in Table 2. In viewing Tables 1 and 2 it can be seen that there is very good agreement among the tests. The deviation between corresponding data is generally less than 10 percent.

As would be expected, sulphur oxides were the primary pollutant emitted by the incinerator stack. Values for this are shown in Table 1 and have been expressed as both equivalent SO_2 and S emissions. The average determined rate of SO_2 emission was 49.4 t/d. This is approximately 67.5 percent of the maximum value,

Table 1. Summary of source emission test results.

A.D.R.P. — August 21-22, 1985
Crossfield — File Number 5390-85-1

Parameter	Test One 85/08/21	Test Two 85/08/21	Test Three 85/08/21	Test Four 85/08/22	Test Five 85/08/22	Test Six 85/08/22
Average Gas Temperature - °C	421	420	434	426	432	430
Average Gas Velocity** - m/s	15.983	16.387	16.406	16.738	16.730	16.905
Total Stream Flow Rate*						
- m^3/s	62.184	63.805	62.632	64.673	64.103	64.980
- kmols/h	9269.965	9511.598	9336.730	9640.906	9555.965	9686.703
Water Content - mole %	20.63	21.07	21.37	20.51	21.34	20.97
Oxides of Sulphur						
Wet Concentration - mole %	0.3372	0.3276	0.3460	0.3365	0.3401	0.3389
Flow Rate* - m^3/s	0.210	0.209	0.217	0.218	0.218	0.220
Emission as SO_2 - t/d	48.117	47.966	49.726	49.933	50.020	50.534
as S - t/d	24.059	23.983	24.863	24.966	25.010	25.267
Oxides of Nitrogen						
Wet Concentration - ppm	4	6	0***	9	4	0***
Flow Rate* - m^3/s	0.0002	0.0004	-	0.0006	0.0003	-
Emission as NO_2 - t/d	0.041	0.063	-	0.096	0.042	-
Mass Ratio of NO_X/SO_2 Emissions	0.00085	0.00131	-	0.00192	0.00084	-

* At 21°C and 101.325 kPa, Wet Flow

** Due to the presence of other sampling equipment, a full diameter could not be traversed when measuring the stack velocity. Therefore, two half diameters at 90° were measured.

*** The occurrence of zero NO_X readings for these tests is attributed to leakage problems with the NO_X sample containers.

Table 2. Total flue gas composition - mole percent.

A.D.R.P.
Crossfield

August 21-22, 1985
File Number 5390-85-1

Parameter	Test One 85/08/21	Test Two 85/08/21	Test Three 85/08/21	Test Four 85/02/22	Test Five 85/08/22	Test Six 85/08/22
Hydrogen (H_2)	0.5635	0.5350	0.5149	0.5804	0.5540	0.5534
Argon (Ar)	0.7831	0.7810	0.7759	0.7849	0.7785	0.7815
Oxygen (O_2)	5.6704	5.4726	5.8125	5.4574	5.2220	5.2886
Nitrogen (N_2)	65.4783	65.2777	64.8782	65.6281	65.0975	65.3493
Methane (C_1)	0.1846	0.1733	0.1803	0.1772	0.1787	0.1729
Carbon Monoxide (CO)	0.4632	0.4664	0.4319	0.5063	0.4879	0.4872
Carbon Dioxide (CO_2)	5.8632	5.8494	5.6652	5.9930	5.9781	6.0316
Ethane (C_2)	0.0036	0.0034	0.0038	0.0040	0.0037	0.0041
Ethylene (C_2=)	0.0019	0.0014	0.0013	0.0014	0.0011	0.0022
Hydrogen Sulphide (H_2S)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Carbonyl Sulphide (COS)	0.0132	0.0159	0.0128	0.0130	0.0120	0.0129
Sulphur Dioxide (SO_2)	0.3372	0.3441	0.3460	0.3365	0.3401	0.3389
Carbon Disulphide (CS_2)	0.0058	0.0078	0.0060	0.0057	0.0052	0.0056
Propane+ (C_3+)	0.0016	0.0014	0.0012	0.0012	0.0008	0.0018
Nitrogen Dioxide (NO_2)	0.0004	0.0006	N.D.	0.0009	0.0004	N.D.
Water (H_2O)	20.63	21.07	21.37	20.51	21.34	20.97
Total	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

N.D. - Analyzed for but not detected.

73.2 t/d, for which the plant is licensed to operate under the Clean Air Act.

Only small amounts of nitrogen oxides (NO_x) were emitted, as indicated in Table 1. The average determined NO_x emission rate was 0.061 t/d.

The average mass ratio of NO_x to SO_2 emitted from the stack was 0.00123. Therefore, in comparison to SO_2 emissions, the NO_x emissions from this source are insignificant.

1.5 CONCLUSIONS

In terms of atmospheric pollutants, the incinerator stack at the Crossfield plant is primarily a source of oxides of sulphur emissions. The average determined rate at which oxides of sulphur was emitted was 49.4 t/d (expressed as an SO_2 equivalent). Only small amounts of NO_x were emitted. The average determined NO_x emission rate was 0.061 t/d (expressed as NO_2 equivalent).

1.6 COMPUTER OUTPUT

This section contains the computer output for the primary determinations (i.e., stack gas velocity, volumetric flow rate, gas composition, molecular weight, moisture content, SO_2 concentration and NO_x concentration), graphs showing the velocity profile determined for each traverse, and summaries of the field and laboratory data.

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              ADRP  CROSSFIELD INCINERATOR STACK

                       EMISSION CALCULATIONS


TEST NUMBER  1  PAGE 1                   DATE  AUGUST 21,1985

LOCATION OF SAMPLING POINT                           147 FOOT LEVEL
INSIDE DIAMETER OF STACK AT SAMPLING POINT          3.65 METERS
INSIDE DIAMETER OF STACK AT TOP                     3.65 METERS
BAROMETRIC PRESSURE                               670.56 MM. HG
AMBIENT TEMPERATURE                                  10. DEG.C


CARBON DIOXIDE ANALYSIS
            GAS CHROMATOGRAPHY       7.39  PERCENT-DRY BASIS
OXYGEN ANALYSIS
            GAS CHROMATOGRAPHY       7.15  PERCENT-DRY BASIS


         AVERAGE COMPOSITION OF FLUE GAS

                DRY BASIS     WET BASIS
                 PERCENT       PERCENT

            O2       7.15          5.65
            CO2      7.39          5.84
            N2 *    85.46         67.54
            H2O                   20.63
            SO2                    0.34


   * BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00)    0.940

SULPHUR DIOXIDE ANALYSIS


  GAS SAMPLE METERED              6.38 CU.FT.
  GAS SAMPLE TEMPERATURE           28. DEG.C
  VACUUM AT METER                 0.0  MM.HG.
  VACUUM AT CONDENSER            38.10 MM.HG.
  VOLUME OF WATER COLLECTED      29.00 CC.
  VOLUME OF BA(CLO4)2 USED      556.50 CC.
  NORMALITY OF BA(CLO4)2          0.10 N.
  VAP.PRES.OF H2O-IMPINGER TEMP. 0.28 IN. OF HG.
  AVERAGE SO2 CONCENTRATION     0.3372 PERCENT-WET BASIS

  TOTAL VOL OF GAS SAMPLED        8.07 CU.FT. (METER CONDITIONS)
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            ADRP  CROSSFIELD INCINERATOR STACK

                  EMISSION CALCULATIONS


 TEST NUMBER  1  PAGE 2                 DATE  AUGUST 21,1985

FLUE GAS FLOW RATE

                                     VELOCITY HEAD - IN. H2O
SECTOR   PROBE TIP FROM                  TRAVERSE NUMBER
          WALL-FT.             1
   1         0.190          0.140
   2         0.590          0.200
   3         1.022          0.250
   4         1.495          0.320
   5         2.024          0.360
   6         2.637          0.380
   7         3.390          0.410
   8         4.485          0.440
   8         4.485          0.420
   7         3.390          0.330
   6         2.637          0.400
   5         2.024          0.410
   4         1.495          0.410
   3         1.022          0.370
   2         0.590          0.310
   1         0.190          0.300

AV. SQ. ROOT                0.578

 AVERAGE STATIC PRESSURE                             -3.30 CM. H2O
 AVERAGE FLUE GAS TEMPERATURE                         421. DEG.C
 PITOT TUBE CALIBRATION FACTOR                       0.804
 OVERALL AVERAGE SQUARE ROOT                         0.578
 AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL             15.983   M/SEC - MEAS.
                              STACK TOP                15.983  M/SEC - CALC.
 TOTAL FLUE GAS FLOW RATE                           62.184 M3/S*
                                                    9269.965 KMOLS/HR
 SULPHUR DIOXIDE EMISSION RATE                         0.210 M3/S*
                                                     48.117 TONNE/D SO2
                                                     24.059 TONNE/D SULPHUR

 * VOLUMES EXPRESSED AT 21.1 C AND 760 MM HG
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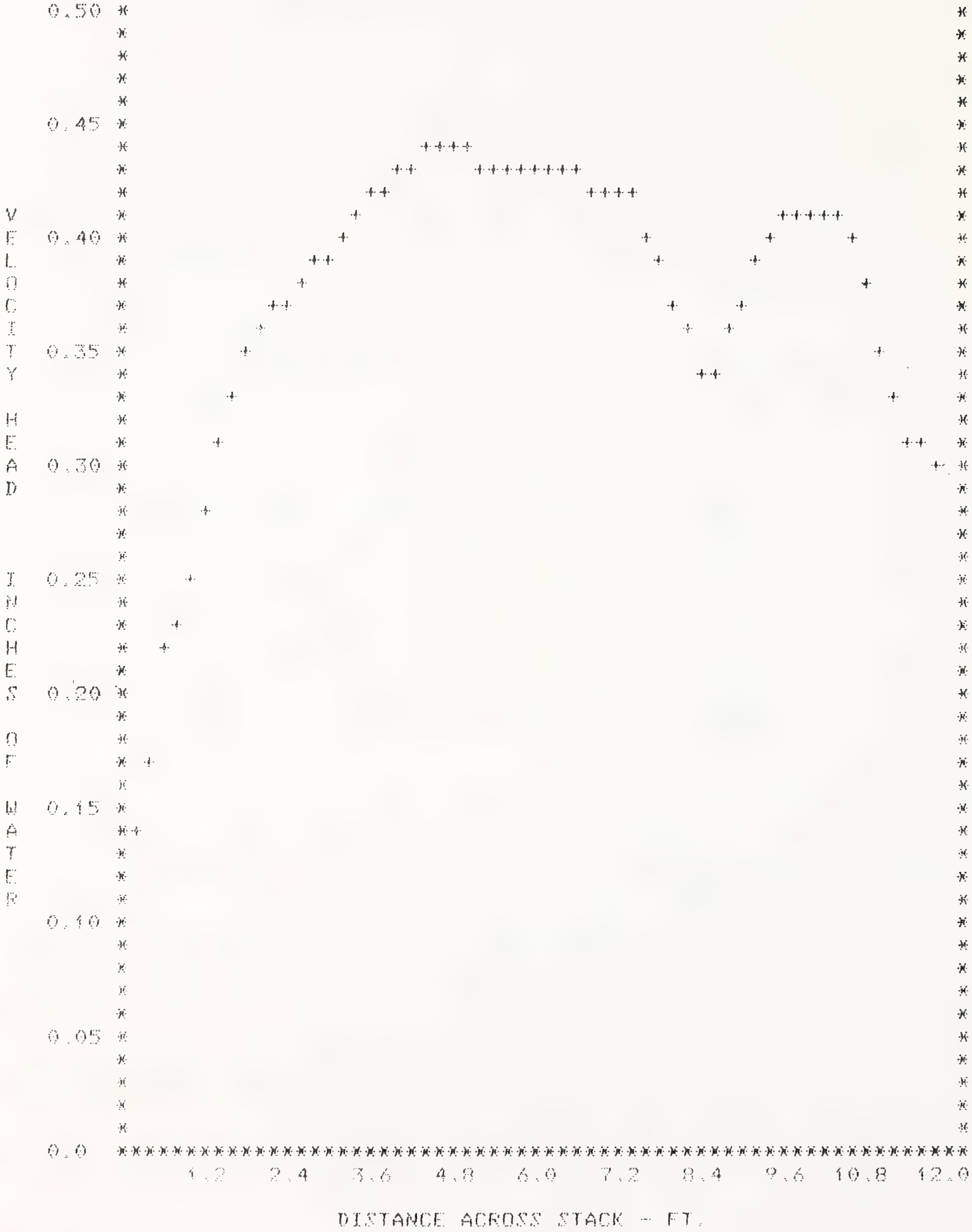

ADRP

VELOCITY PROFILE 1 TEST 1

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          ADRP  CROSSFIELD INCINERATOR STACK

                 EMISSION CALCULATIONS


TEST NUMBER  2  PAGE 1                 DATE  AUGUST 21,1985

LOCATION OF SAMPLING POINT                         147 FOOT LEVEL
INSIDE DIAMETER OF STACK AT SAMPLING POINT        3.65 METERS
INSIDE DIAMETER OF STACK AT TOP                   3.65 METERS
BAROMETRIC PRESSURE                             670.56 MM. HG
AMBIENT TEMPERATURE                                10. DEG.C


CARBON DIOXIDE ANALYSIS
            GAS CHROMATOGRAPHY        7.42  PERCENT-DRY BASIS
OXYGEN ANALYSIS
            GAS CHROMATOGRAPHY        6.94  PERCENT-DRY BASIS


         AVERAGE COMPOSITION OF FLUE GAS

                 DRY BASIS     WET BASIS
                  PERCENT       PERCENT

            O2       6.94          5.46
            CO2      7.42          5.83
            N2 *    85.64         67.32
            H2O                   21.07
            SO2                    0.33


   * BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00)    0.938

SULPHUR DIOXIDE ANALYSIS


  GAS SAMPLE METERED             12.81 CU.FT.
  GAS SAMPLE TEMPERATURE           38. DEG.C
  VACUUM AT METER                 0.0  MM.HG.
  VACUUM AT CONDENSER            50.80 MM.HG.
  VOLUME OF WATER COLLECTED      58.00 CC.
  VOLUME OF BA(CLO4)2 USED     1058.00 CC.
  NORMALITY OF BA(CLO4)2          0.10 N.
  VAP.PRES.OF H2O-IMPINGER TEMP. 0.28 IN. OF HG.
  AVERAGE SO2 CONCENTRATION    0.3276 PERCENT-WET BASIS

  TOTAL VOL OF GAS SAMPLED      16.30 CU.FT. (METER CONDITIONS)
```

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              ADRP  CROSSFIELD INCINERATOR STACK

                     EMISSION CALCULATIONS


  TEST NUMBER  2  PAGE 2                  DATE  AUGUST 21,1985

 FLUE GAS FLOW RATE

                                        VELOCITY HEAD - IN. H2O
 SECTOR   PROBE TIP FROM                    TRAVERSE NUMBER
           WALL-FT.            1
    1          0.190         0.140
    2          0.590         0.250
    3          1.022         0.330
    4          1.495         0.350
    5          2.024         0.370
    6          2.637         0.400
    7          3.390         0.400
    8          4.485         0.410
    8          4.485         0.410
    7          3.390         0.430
    6          2.637         0.420
    5          2.024         0.410
    4          1.495         0.410
    3          1.022         0.350
    2          0.590         0.320
    1          0.190         0.300

 AV. SQ. ROOT                0.593


  AVERAGE STATIC PRESSURE                           -3.30 CM. H2O
  AVERAGE FLUE GAS TEMPERATURE                       420. DEG.C
  PITOT TUBE CALIBRATION FACTOR                     0.804
  OVERALL AVERAGE SQUARE ROOT                       0.593
  AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL           16.387   M/SEC - MEAS.
                               STACK TOP              16.387  M/SEC - CALC.
  TOTAL FLUE GAS FLOW RATE                         63.805 M3/S*
                                                   9511.598 KMOLS/HR
  SULPHUR DIOXIDE EMISSION RATE                       0.209 M3/S*
                                                    47.966 TONNE/D SO2
                                                    23.983 TONNE/D SULPHUR

  * VOLUMES EXPRESSED AT 21.1 C AND 760 MM HG
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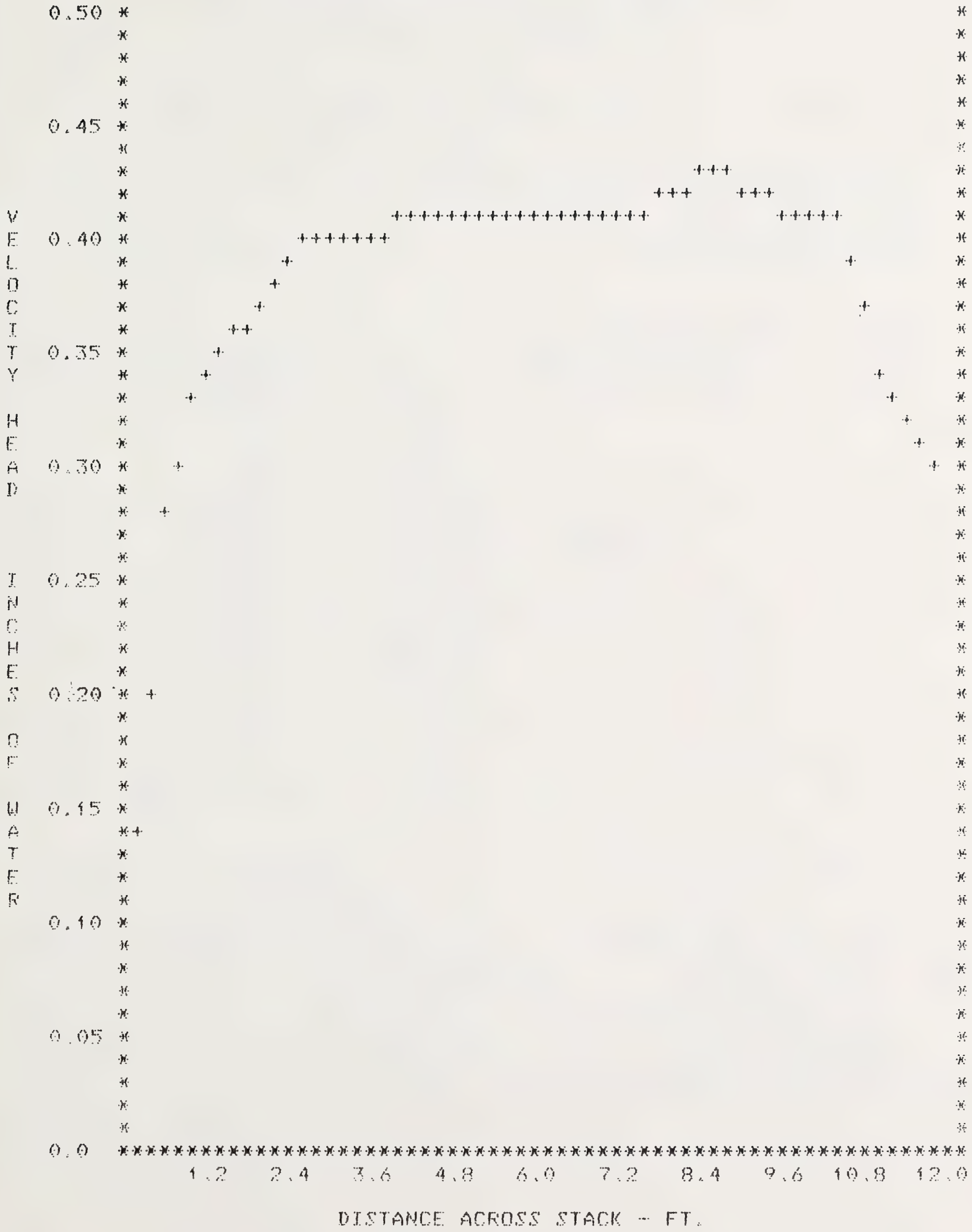
ADRP

VELOCITY PROFILE 1 TEST 2



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           ADRP  CROSSFIELD INCINERATOR STACK

                  EMISSION CALCULATIONS


TEST NUMBER  3  PAGE 1                   DATE  AUGUST 21,1985

LOCATION OF SAMPLING POINT                        147 FOOT LEVEL
INSIDE DIAMETER OF STACK AT SAMPLING POINT       3.65 METERS
INSIDE DIAMETER OF STACK AT TOP                  3.65 METERS
BAROMETRIC PRESSURE                            670.56 MM. HG
AMBIENT TEMPERATURE                               10. DEG.C


CARBON DIOXIDE ANALYSIS
            GAS CHROMATOGRAPHY       7.21  PERCENT-DRY BASIS
OXYGEN ANALYSIS
            GAS CHROMATOGRAPHY       7.40  PERCENT-DRY BASIS


         AVERAGE COMPOSITION OF FLUE GAS

                 DRY BASIS     WET BASIS
                  PERCENT       PERCENT

            O2       7.40          5.79
            CO2      7.21          5.64
            N2 *    85.39         66.85
            H2O                   21.37
            SO2                    0.35

    * BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00)    0.937

SULPHUR DIOXIDE ANALYSIS


  GAS SAMPLE METERED                 12.19 CU.FT.
  GAS SAMPLE TEMPERATURE               39. DEG.C
  VACUUM AT METER                    0.0   MM.HG.
  VACUUM AT CONDENSER                50.80 MM.HG.
  VOLUME OF WATER COLLECTED          56.00 CC.
  VOLUME OF BA(CLO4)2 USED         1063.60 CC.
  NORMALITY OF BA(CLO4)2              0.10 N.
  VAP.PRES.OF H2O-IMPINGER TEMP.  0.28 IN. OF HG.
  AVERAGE SO2 CONCENTRATION        0.3460 PERCENT-WET BASIS

  TOTAL VOL OF GAS SAMPLED           15.57 CU.FT. (METER CONDITIONS)
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            ADRP  CROSSFIELD INCINERATOR STACK

                   EMISSION CALCULATIONS


 TEST NUMBER  3  PAGE 2                 DATE  AUGUST 21,1985

FLUE GAS FLOW RATE

                                  VELOCITY HEAD - IN. H20
SECTOR   PROBE TIP FROM               TRAVERSE NUMBER
          WALL-FT.                1
   1          0.190             0.170
   2          0.590             0.230
   3          1.022             0.320
   4          1.495             0.370
   5          2.024             0.390
   6          2.637             0.410
   7          3.390             0.430
   8          4.485             0.450
   8          4.485             0.430
   7          3.390             0.410
   6          2.637             0.410
   5          2.024             0.370
   4          1.495             0.360
   3          1.022             0.330
   2          0.590             0.290
   1          0.190             0.230

AV. SQ. ROOT                    0.587


 AVERAGE STATIC PRESSURE                         -3.30 CM. H20
 AVERAGE FLUE GAS TEMPERATURE                     434. DEG.C
 PITOT TUBE CALIBRATION FACTOR                   0.804
 OVERALL AVERAGE SQUARE ROOT                     0.587
 AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL         16.406   M/SEC - MEAS.
                              STACK TOP            16.406  M/SEC - CALC.
 TOTAL FLUE GAS FLOW RATE                       62.632 M3/S*
                                                9336.730 KMOLS/HR
 SULPHUR DIOXIDE EMISSION RATE                     0.217 M3/S*
                                                 49.726 TONNE/D SO2
                                                 24.863 TONNE/D SULPHUR

 * VOLUMES EXPRESSED AT 21.1 C AND 760 MM HG
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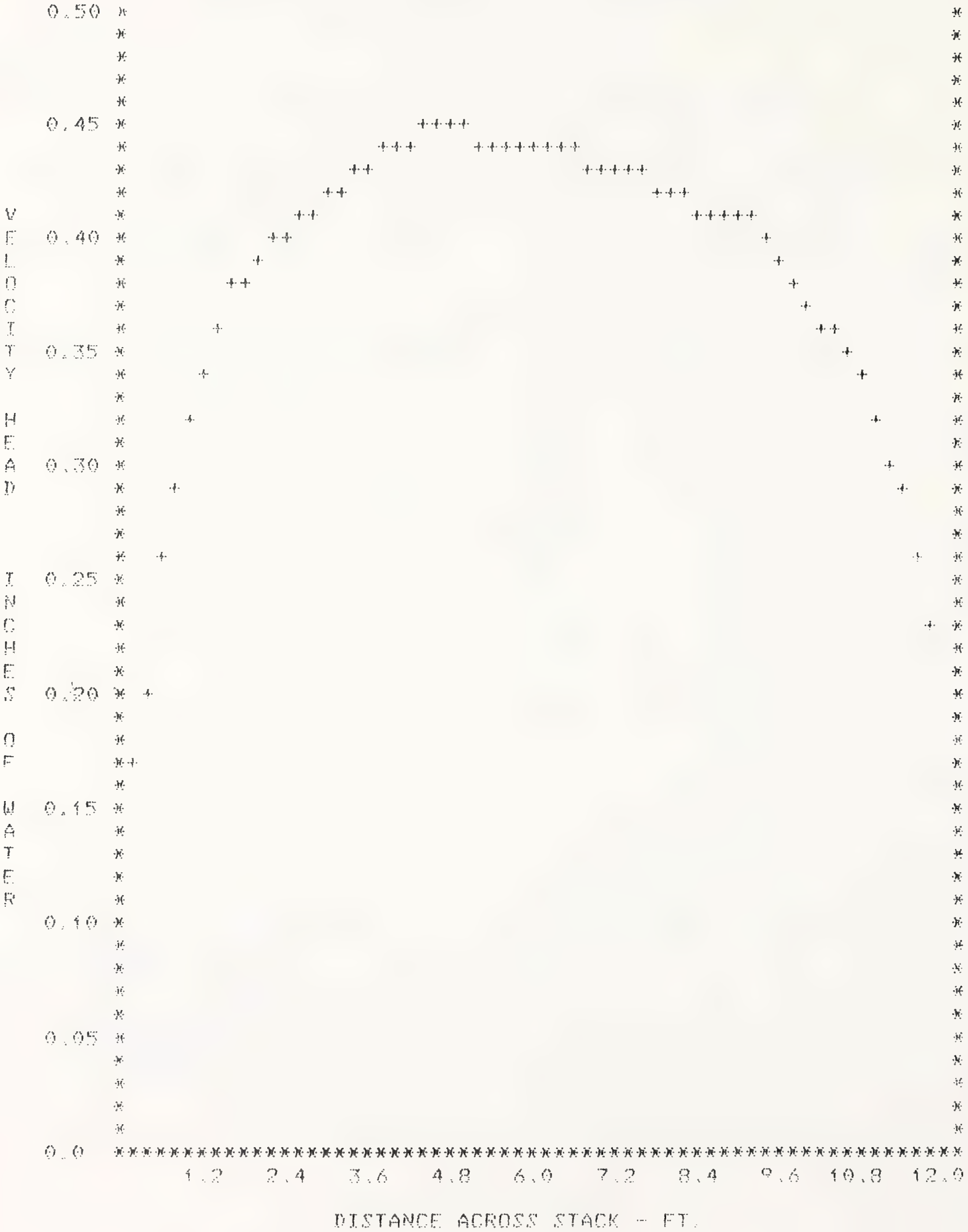
ADRP

VELOCITY PROFILE 1 TEST 3



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          ADRP  CROSSFIELD INCINERATOR STACK

                 EMISSION CALCULATIONS


TEST NUMBER  4  PAGE 1                  DATE  AUGUST 22,1985

LOCATION OF SAMPLING POINT                          147 FOOT LEVEL
INSIDE DIAMETER OF STACK AT SAMPLING POINT         3.65 METERS
INSIDE DIAMETER OF STACK AT TOP                    3.65 METERS
BAROMETRIC PRESSURE                              671.32 MM. HG
AMBIENT TEMPERATURE                                 24. DEG.C


CARBON DIOXIDE ANALYSIS
           GAS CHROMATOGRAPHY        7.55  PERCENT-DRY BASIS
OXYGEN ANALYSIS
           GAS CHROMATOGRAPHY        6.87  PERCENT-DRY BASIS


        AVERAGE COMPOSITION OF FLUE GAS

               DRY BASIS     WET BASIS
                PERCENT       PERCENT

           O2       6.87         5.44
           CO2      7.55         5.98
           N2 *    85.58        67.74
           H2O                  20.51
           SO2                   0.34


   * BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00)     0.941

SULPHUR DIOXIDE ANALYSIS


  GAS SAMPLE METERED              13.70 CU.FT.
  GAS SAMPLE TEMPERATURE            46. DEG.C
  VACUUM AT METER                  0.0  MM.HG.
  VACUUM AT CONDENSER             50.80 MM.HG.
  VOLUME OF WATER COLLECTED       58.00 CC.
  VOLUME OF BA(CLO4)2 USED      1124.20 CC.
  NORMALITY OF BA(CLO4)2           0.10 N.
  VAP.PRES.OF H2O-IMPINGER TEMP.  0.31 IN. OF HG.
  AVERAGE SO2 CONCENTRATION     0.3365 PERCENT-WET BASIS

  TOTAL VOL OF GAS SAMPLED        17.31 CU.FT. (METER CONDITIONS)
```

```
              ADRP  CROSSFIELD INCINERATOR STACK

                    EMISSION CALCULATIONS


 TEST NUMBER  4  PAGE 2                DATE  AUGUST 22,1985

FLUE GAS FLOW RATE

                                  VELOCITY HEAD - IN. H2O
SECTOR   PROBE TIP FROM              TRAVERSE NUMBER
           WALL-FT.            1
   1          0.190          0.190
   2          0.590          0.310
   3          1.022          0.330
   4          1.495          0.380
   5          2.024          0.390
   6          2.637          0.420
   7          3.390          0.410
   8          4.485          0.420
   8          4.485          0.430
   7          3.390          0.410
   6          2.637          0.410
   5          2.024          0.410
   4          1.495          0.410
   3          1.022          0.380
   2          0.590          0.310
   1          0.190          0.280

AV. SQ. ROOT                 0.604

 AVERAGE STATIC PRESSURE                             -3.56 CM. H2O
 AVERAGE FLUE GAS TEMPERATURE                         426. DEG.C
 PITOT TUBE CALIBRATION FACTOR                       0.804
 OVERALL AVERAGE SQUARE ROOT                         0.604
 AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL             16.738   M/SEC - MEAS.
                              STACK TOP                16.738  M/SEC - CALC.
 TOTAL FLUE GAS FLOW RATE                           64.673 M3/S*
                                                    9640.906 KMOLS/HR
 SULPHUR DIOXIDE EMISSION RATE                         0.218 M3/S*
                                                     49.933 TONNE/D SO2
                                                     24.966 TONNE/D SULPHUR

 * VOLUMES EXPRESSED AT 21.1 C AND 760 MM HG
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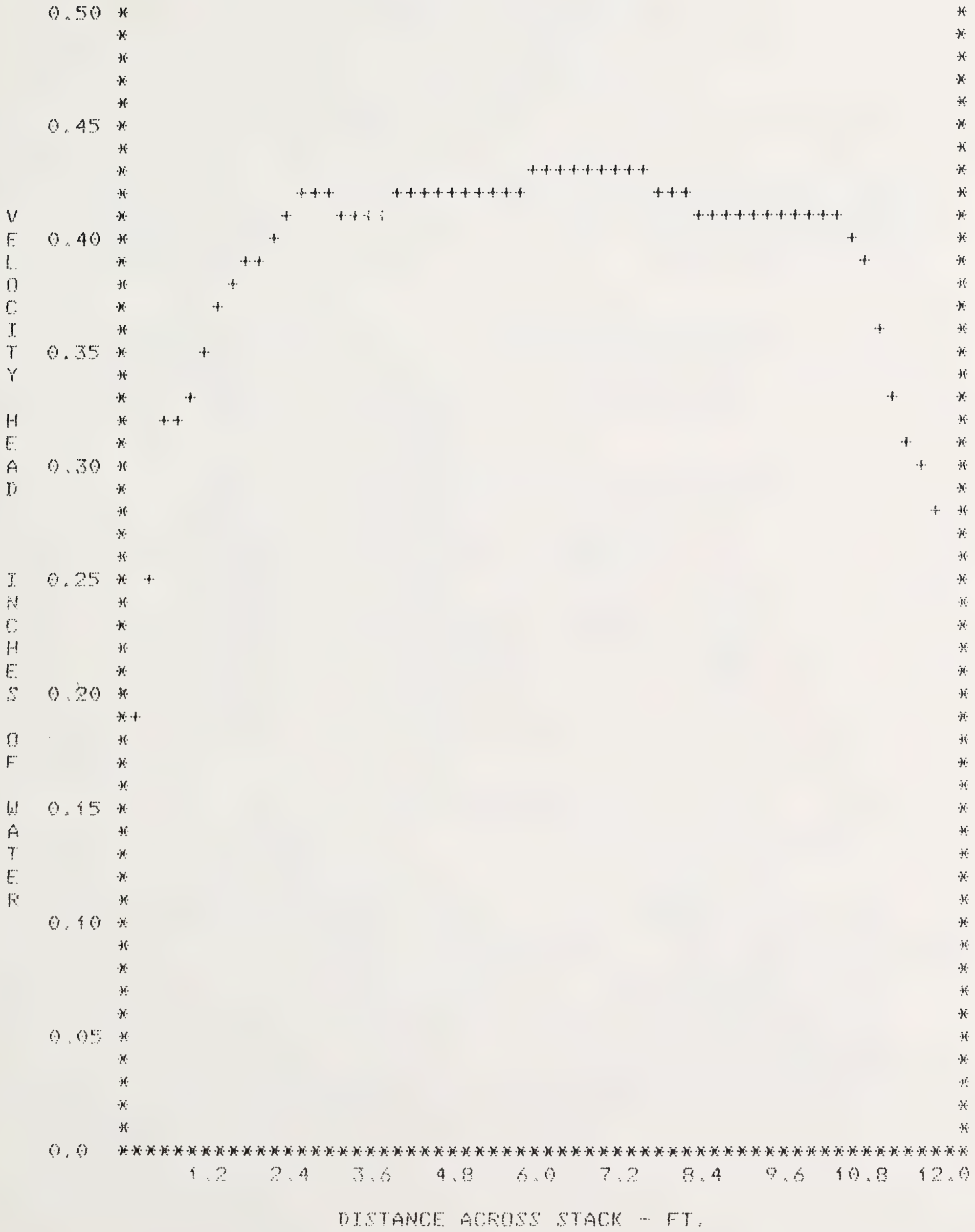
ADRP

VELOCITY PROFILE 1 TEST 4



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                 ADRP  CROSSFIELD INCINERATOR STACK

                        EMISSION CALCULATIONS


TEST NUMBER  5  PAGE 1                DATE  AUGUST 22,1985

LOCATION OF SAMPLING POINT                               147 FOOT LEVEL
INSIDE DIAMETER OF STACK AT SAMPLING POINT              3.65 METERS
INSIDE DIAMETER OF STACK AT TOP                         3.65 METERS
BAROMETRIC PRESSURE                                   671.32 MM. HG
AMBIENT TEMPERATURE                                      24. DEG.C


CARBON DIOXIDE ANALYSIS
            GAS CHROMATOGRAPHY       7.61  PERCENT-DRY BASIS
OXYGEN ANALYSIS
            GAS CHROMATOGRAPHY       6.65  PERCENT-DRY BASIS


         AVERAGE COMPOSITION OF FLUE GAS

                 DRY BASIS     WET BASIS
                  PERCENT       PERCENT

            O2       6.65          5.21
            CO2      7.61          5.96
            N2 *    85.74         67.16
            H2O                   21.34
            SO2                    0.34


   * BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00)    0.938

SULPHUR DIOXIDE ANALYSIS


  GAS SAMPLE METERED             13.52 CU.FT.
  GAS SAMPLE TEMPERATURE           49. DEG.C
  VACUUM AT METER                 0.0  MM.HG.
  VACUUM AT CONDENSER            50.80 MM.HG.
  VOLUME OF WATER COLLECTED      60.00 CC.
  VOLUME OF BA(CLO4)2 USED     1122.80 CC.
  NORMALITY OF BA(CLO4)2          0.10 N.
  VAP.PRES.OF H2O-IMPINGER TEMP. 0.29 IN. OF HG.
  AVERAGE SO2 CONCENTRATION     0.3401 PERCENT-WET BASIS

  TOTAL VOL OF GAS SAMPLED       17.26 CU.FT. (METER CONDITIONS)
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            ADRP  CROSSFIELD INCINERATOR STACK

                   EMISSION CALCULATIONS


 TEST NUMBER  5  PAGE 2                  DATE  AUGUST 22,1985

FLUE GAS FLOW RATE

                                          VELOCITY HEAD - IN. H2O
SECTOR   PROBE TIP FROM                       TRAVERSE NUMBER
           WALL-FT.              1
   1         0.190           0.200
   2         0.590           0.280
   3         1.022           0.350
   4         1.495           0.380
   5         2.024           0.400
   6         2.637           0.440
   7         3.390           0.430
   8         4.485           0.430
   8         4.485           0.410
   7         3.390           0.430
   6         2.637           0.420
   5         2.024           0.420
   4         1.495           0.390
   3         1.022           0.330
   2         0.590           0.270
   1         0.190           0.250

AV. SQ. ROOT                 0.600


 AVERAGE STATIC PRESSURE                             -3.56 CM. H2O
 AVERAGE FLUE GAS TEMPERATURE                         432. DEG.C
 PITOT TUBE CALIBRATION FACTOR                       0.804
 OVERALL AVERAGE SQUARE ROOT                         0.600
 AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL             16.730   M/SEC - MEAS.
                              STACK TOP                16.730  M/SEC - CALC.
 TOTAL FLUE GAS FLOW RATE                           64.103 M3/S*
                                                    9555.965 KMOLS/HR
 SULPHUR DIOXIDE EMISSION RATE                         0.218 M3/S*
                                                     50.020 TONNE/D SO2
                                                     25.010 TONNE/D SULPHUR

 * VOLUMES EXPRESSED AT 21.1 C AND 760 MM HG
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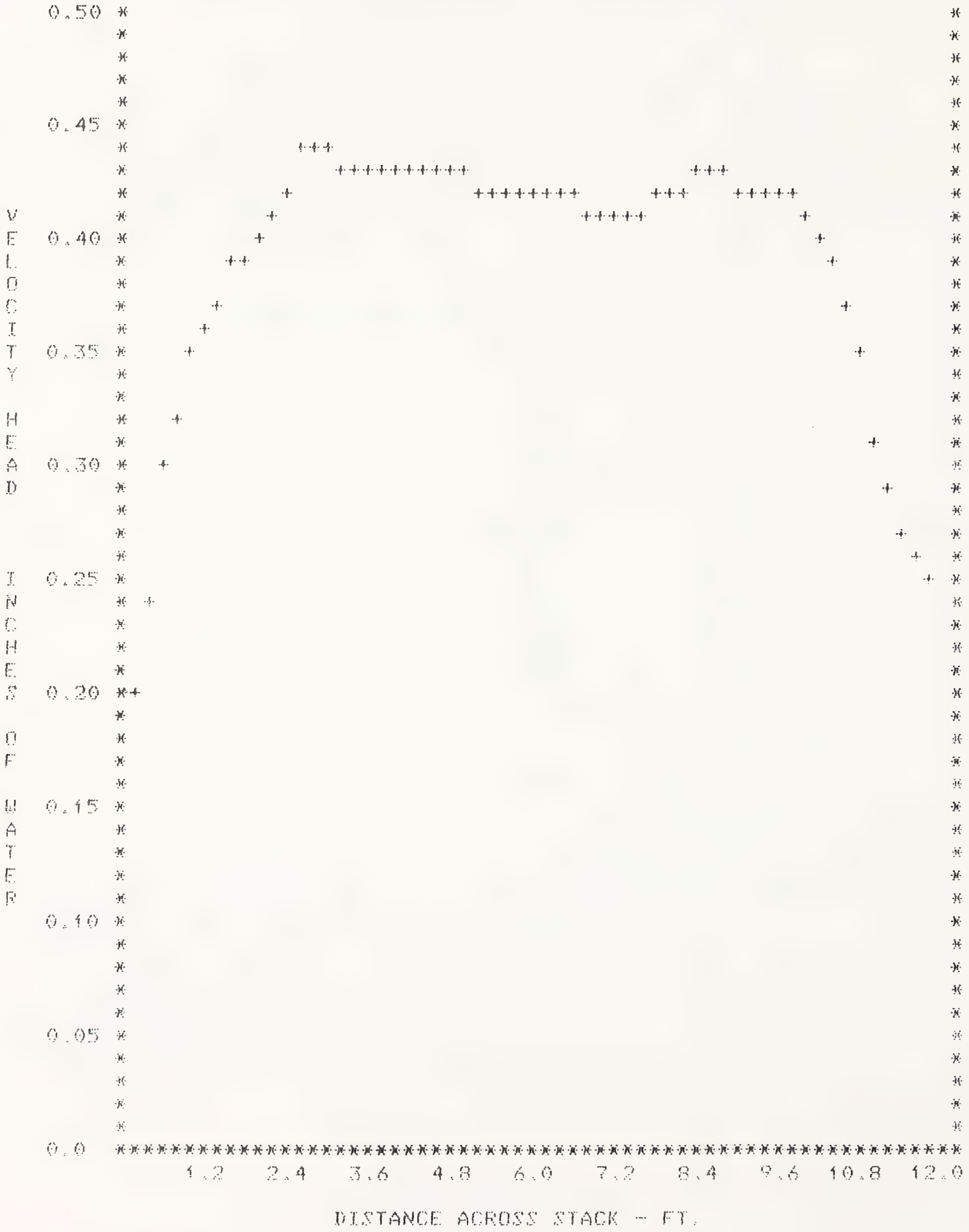
ADRP

VELOCITY PROFILE 1 TEST 5



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          ADRP  CROSSFIELD INCINERATOR STACK

                EMISSION CALCULATIONS


TEST NUMBER  6  PAGE 1                 DATE  AUGUST 22,1985

LOCATION OF SAMPLING POINT                          147 FOOT LEVEL
INSIDE DIAMETER OF STACK AT SAMPLING POINT         3.65 METERS
INSIDE DIAMETER OF STACK AT TOP                    3.65 METERS
BAROMETRIC PRESSURE                              671.32 MM. HG
AMBIENT TEMPERATURE                                 24. DEG.C


CARBON DIOXIDE ANALYSIS
           GAS CHROMATOGRAPHY        7.64  PERCENT-DRY BASIS
OXYGEN ANALYSIS
           GAS CHROMATOGRAPHY        6.70  PERCENT-DRY BASIS


        AVERAGE COMPOSITION OF FLUE GAS

               DRY BASIS     WET BASIS
                PERCENT       PERCENT

           O2      6.70          5.27
           CO2     7.64          6.01
           N2 *   85.66         67.41
           H2O                  20.97
           SO2                   0.34


   * BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00)     0.939

SULPHUR DIOXIDE ANALYSIS


  GAS SAMPLE METERED             13.05 CU.FT.
  GAS SAMPLE TEMPERATURE           52. DEG.C
  VACUUM AT METER                 0.0  MM.HG.
  VACUUM AT CONDENSER            50.80 MM.HG.
  VOLUME OF WATER COLLECTED      56.00 CC.
  VOLUME OF BA(CLO4)2 USED     1065.00 CC.
  NORMALITY OF BA(CLO4)2          0.10 N.
  VAP.PRES.OF H2O-IMPINGER TEMP. 0.30 IN. OF HG.
  AVERAGE SO2 CONCENTRATION     0.3389 PERCENT-WET BASIS

  TOTAL VOL OF GAS SAMPLED       16.58 CU.FT. (METER CONDITIONS)
```

```
            ADRP  CROSSFIELD INCINERATOR STACK

                   EMISSION CALCULATIONS


 TEST NUMBER  6  PAGE 2                 DATE  AUGUST 22.1985

FLUE GAS FLOW RATE

                                  VELOCITY HEAD - IN. H2O
SECTOR   PROBE TIP FROM               TRAVERSE NUMBER
          WALL-FT.            1
   1         0.190          0.200
   2         0.590          0.270
   3         1.022          0.350
   4         1.495          0.390
   5         2.024          0.420
   6         2.637          0.430
   7         3.390          0.440
   8         4.485          0.400
   8         4.485          0.410
   7         3.390          0.420
   6         2.637          0.450
   5         2.024          0.400
   4         1.495          0.420
   3         1.022          0.360
   2         0.590          0.320
   1         0.190          0.290

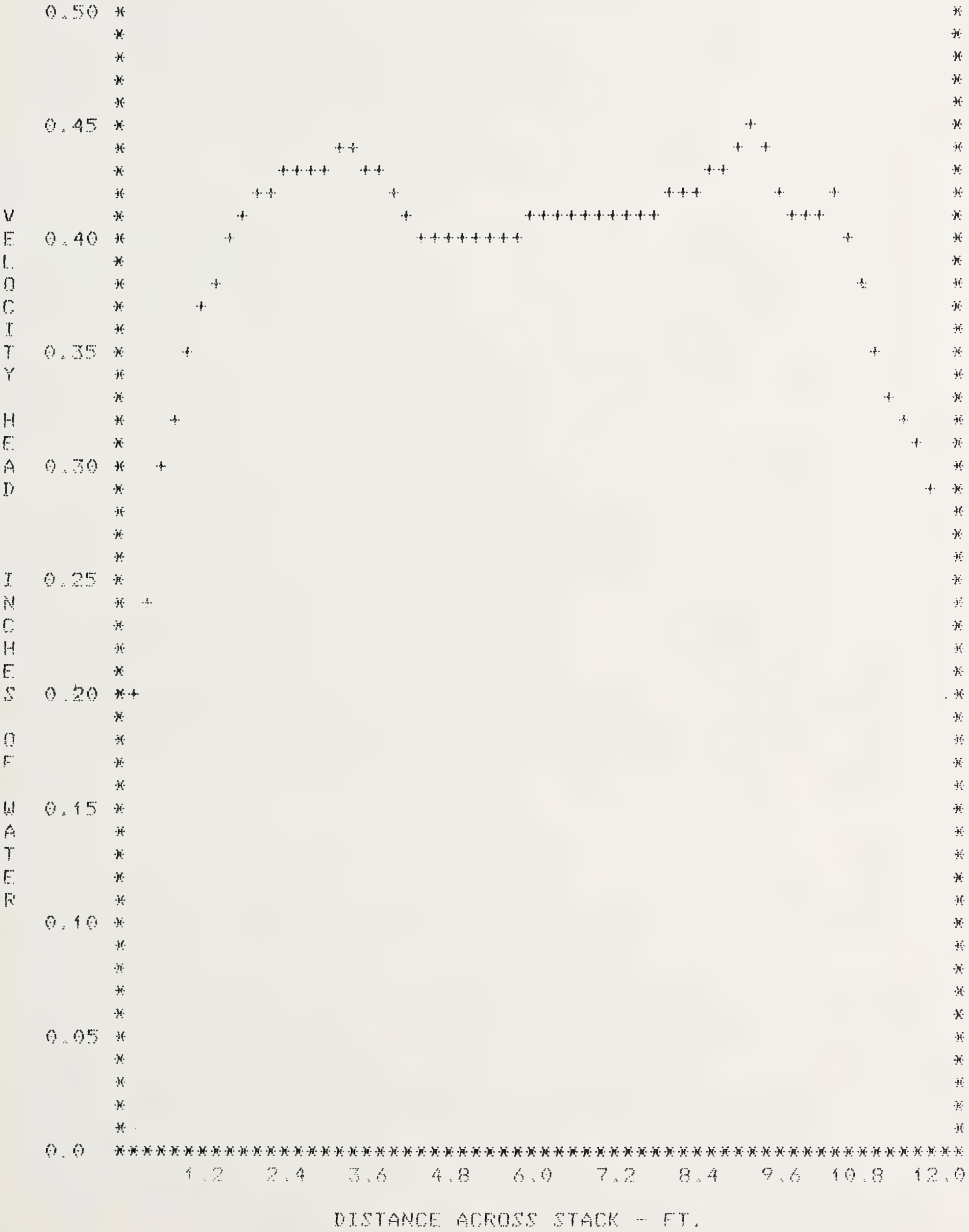
AV. SQ. ROOT                0.608

 AVERAGE STATIC PRESSURE                        -3.56 CM. H2O
 AVERAGE FLUE GAS TEMPERATURE                    430. DEG.C
 PITOT TUBE CALIBRATION FACTOR                  0.804
 OVERALL AVERAGE SQUARE ROOT                    0.608
 AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL        16.905   M/SEC - MEAS.
                              STACK TOP           16.905  M/SEC - CALC.
 TOTAL FLUE GAS FLOW RATE                      64.980 M3/S*
                                               9686.703 KMOLS/HR
 SULPHUR DIOXIDE EMISSION RATE                    0.220 M3/S*
                                                50.534 TONNE/D SO2
                                                25.267 TONNE/D SULPHUR

 *  VOLUMES EXPRESSED AT 21.1 C AND 760 MM HG
```

ADRP

VELOCITY PROFILE 1 TEST 6



GAS CHROMATOGRAPHIC ANALYSES

A.D.R.P.
CROSSFIELD

AUGUST 21/22.1985
FILE NUMBER 5390

SITE	08/21	08/21	08/21	08/22	08/22	08/22
TIME	12.22	14.09	15.16	16.46	17.19	18.40
H2	0.7107	0.6783	0.6557	0.7307	0.7051	0.7008
A	0.9877	0.9902	0.9881	0.9882	0.9909	0.9897
O2	7.1516	6.9385	7.4020	6.8709	6.6464	6.6972
N2	82.5824	82.7902	82.6202	82.6268	82.8535	82.7542
C1	0.2328	0.2197	0.2296	0.2231	0.2274	0.2190
CO	0.5842	0.5913	0.5500	0.6375	0.6210	0.6169
CO2	7.3947	7.4162	7.2144	7.5453	7.6087	7.6381
C2+	0.0089	0.0078	0.0080	0.0083	0.0071	0.0102
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
COS	0.0166	0.0159	0.0163	0.0164	0.0153	0.0163
SO2	0.3231	0.3441	0.3081	0.3456	0.3180	0.3505
CS2	0.0073	0.0078	0.0076	0.0072	0.0066	0.0071
TOTAL	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

MOLE PERCENT ON DRY BASIS

WESTERN RESEARCH,CALGARY,ALBERTA

```
                 OXIDES OF NITROGEN DETERMINATION
                            FIELD DATA
-----------------------------------------------------------------
FILE #    5390                                           08/22/85
A.D.R.P.                                         TEMP(C)       24
     CROSSFIELD                                  B.P. MM    671.3
INCINERATOR STACK                                   BY  R.T./M.T.
=================================================================
                              VOLUME       EVAC.    FILLED   FLASK
FLASK     TIME      SOLN.     FLASK        PRES.    PRES.    TEMP.
=================================================================
 7        16.15     30           2073.50 627.4     -2.5      24
 17       16.18     30           2102.80 621        0        24
 6        17.52     30           2033.40 624.8      0        24
 11       17.54     30           2086.60 617.2     -2.5      24
 4        18.16     30           2105.20 622.3      0        24
 10       18.21     30           2080.70 622.3      0        24
=================================================================
=================================================================
                             LAB DATA
-----------------------------------------------------------------
08/26/85                                      CALIBRATION DATA
TEMP (C)         20                           SLOPE         .8823
B.P. MM       678.7                           INTERCEPT      .018
=================================================================
FLASK     PRESSURE TEMP.               ABS.      DILUTION PPM  NO2
=================================================================
 7          -48.3     20               .01                    8.89
 17         -30.5     20               .01                    8.59
 6          -40.6     20               .01                    8.99
 11         -40.6     20               0                      0.00
 4          -17.8     20               0                      0.00
 10         -30.5     20               0                      0.00
=================================================================
=================================================================
                OXIDES OF NITROGEN DETERMINATION
                          FIELD DATA
--------------------------------------------------------------
FILE #    5390                                        08/21/85
A.D.R.P.                                      TEMP(C)       10
      CROSSFIELD                              B.P. MM    670.6
INCINERATOR STACK                                BY  R.T./M.T.
==============================================================
                        VOLUME     EVAC.    FILLED   FLASK
FLASK    TIME     SOLN.    FLASK   PRES.    PRES.    TEMP.
==============================================================
 34      12.28     30          2001.00 614.7     0        11
 30      12.31     30          2012.00 617.2     0        11
 31      14.13     30          2007.00 619.8     0        11
 32      14.16     30          2002.00 617.2     0        11
 15      15.01     30          2027.30 619.8     0        11
 3       15.03     30          2054.30 619.8     0        11
==============================================================
==============================================================
                          LAB DATA
--------------------------------------------------------------
08/26/85                                    CALIBRATION DATA
TEMP (C)        20                          SLOPE        .8823
B.P. MM      678.7                          INTERCEPT     .018
==============================================================
FLASK    PRESSURE TEMP.              ABS.     DILUTION PPM  NO2
==============================================================
 34       -5.1     20                 0                   0.00
 30       0        20                .01                  8.63
 31       5.1      20                .02                 11.35
 32       -7.6     20                 0                   0.00
 15       -17.8    20                 0                   0.00
 3        0        20                 0                   0.00
==============================================================
==============================================================


WESTERN RESEARCH, CALGARY, ALBERTA                      VC-101
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2. NO_x SOURCE SAMPLING PROGRAM

In addition to the testing work conducted at one of the sour gas (extraction) plants located near Crossfield (see Section 1), a source sampling program was conducted in order to establish Alberta specific NO_x emission factors for natural gas fueled reciprocating and turbine engines. These are the major industrial sources of NO_x emissions in Alberta, accounting for approximately three quarters of the total NO_x emissions by industrial sources. Waste gas incinerators were also included in the program as there was some question regarding the importance of these as NO_x emission sources.

Initially eighteen sources were surveyed (i.e., six reciprocating engines, six turbine engines and three waste gas incinerator units), with intentions to conduct additional sampling following a preliminary review of the survey results. The preliminary results indicated that the waste gas incinerators used in Alberta are not significant sources of NO_x emissions. The average NO_x emission rate of 0.0337 t/d which was determined is roughly that which a 100 kW natural gas fueled reciprocating engine would be expected to produce. The preliminary results also indicated that the variability of NO_x emission factor values for reciprocating engines is quite high, with the precision of these (i.e., the mean divided by the standard deviation), being in excess of a value of 1.0. The precision of NO_x emission factor values determined for the turbine engines was less than half this value.

In view of the poor precision of the NO_x emission factors determined for reciprocating engines it was decided to survey six more of these units. No additional waste gas incinerator units or turbine engines were surveyed.

For each of the twenty-one NO_x emission sources surveyed (i.e., twelve reciprocating engines, six turbine engines and three waste gas incinerator units), a formal report was prepared which identifies the sampling and analysis methods used, delineates the analytic procedures employed, and tabulates the field and laboratory data. These are presented in the following subsections:

Section 2.1 - Individual Reports of the Reciprocating Engines

Section 2.2 - Individual Reports of the Turbine Engines

Section 2.3 - Individual Reports of the Waste Gas Incinerator Units

The publications which are referenced in these reports are listed in Section 2.4.

The overall results of the NO_x source sampling program are summarized and discussed in Volume 2, Section 3.2.3.

2.1 INDIVIDUAL REPORTS OF THE SURVEYED RECIPROCATING ENGINES

The individual reports that were prepared for each the twenty-one reciprocating engines surveyed are presented in the following. Since the Introduction and Procedure sections of each report are basically the same, these have been omitted from all but the first report to avoid duplication.

2.1.1 Natural Gas Fueled Engines: NO_x Test Report No. R-1

Test Date: October 7, 1985
Test Location: Sylvan Lake area
Tested By: M. Towill & B. Reshetylo

2.1.1.1 Summary

A 600 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 83.8 ng/J was obtained. This is approximately 94% lower than the value of 1481 ng/J (55 400 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency (1985) for typical industrial natural gas fueled reciprocating engines. The significantly lower emission factor obtained here is likely due to the rich fuel-air mixture (i.e., insufficient air for stoichiometric combustion) on which the engine operated. With such a fuel mixture, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of NO_x.

2.1.1.2 Introduction

In Alberta, the primary industrial source of NOx emissions is the internal combustion engine (i.e., large turbine and reciprocating engines). The amount of NO_x emitted from these units is normally estimated by using emission factors. Emission factors express NO_x emissions in terms of nanograms per joule of fuel consumed (ng/J).

Production of NO_x is a complex process. Ambient temperature, pressure and humidity, and operating conditions are all known to have a significant effect. Subsequently, the use of emission factors provides only a rough approximation of actual emissions. In order to obtain NO_x emission factors that will best approximate NO_x emissions in Alberta, a number of representative emission sources are being tested (Alberta-specific emission factors are not currently available).

In Alberta, the vast majority of industrial turbine and reciprocating engines are natural gas fueled. Therefore, only natural gas fueled engines are being considered.

A minimum of six turbine engines and six reciprocating engines of various power levels will be tested. In this report, NO_x testing of a 600 kW reciprocating engine is discussed.

2.1.1.3 Procedure

(1) The following basic data were recorded:

- location,
- date,
- ambient temperature,
- relative humidity,
- barometric pressure,
- test crew, and
- test unit description.

(2) One duplicate flue gas sample and one fuel gas sample were collected and subsequently analyzed by a gas chromatograph. These analyses were used to obtain a single representative NOx and H_2O free composition of both the fuel and flue gases.

(3) The moisture content of the flue gas was determined using a half hour condensation test as described under Method 3 in the Alberta Environment Stack Sampling Code (1976).

Any natural gas mixture supplied as fuel to an internal combustion engine will contain much less than 1% H_2O. Moisture levels of this magnitude are insignificant in terms of calculating NO_x emission factors. Therefore, moisture content of the fuel gas was not determined.

(4) The NO_x content of the flue gas was determined using the NO_x testing procedure described under Method 6 in the Alberta Environment Stack Sampling Code (1976). Two triplicate tests were performed (i.e., 6 NO_x samples were taken). Results of these tests were used to obtain a single representative NOx concentration for the flue gas.

(5) Using the results of (2), (3) and (4) an overall representative composition was determined for the flue gas. The overall reaction for the combustion process is expressed as:

$$\begin{bmatrix}\text{Overall}\\ \text{Fuel Gas}\\ \text{Composition}\end{bmatrix} + a \begin{bmatrix}\text{Overall}\\ \text{Composition}\\ \text{of the Air}\end{bmatrix} \rightarrow b \begin{bmatrix}\text{Overall}\\ \text{Flue Gas}\\ \text{Composition}\end{bmatrix} \qquad (1)$$

where "a" and "b" are stoichiometric coefficients. If it is assumed that the concentration of carbon compounds is negligible in the air then the coefficient "b" may be obtained by balancing the carbon atoms between the fuel gas and the flue gas compositions.

An analysis of the air was not conducted nor was "a" evaluated, as this information was not required.

The NO_x emission factor was calculated using the following equation:

$$EF = \frac{y\ (NO_x) \cdot b \cdot M\ (NO_2) \cdot g_c}{\text{100 kmoles of fuel gas} \cdot \Delta H} \tag{2}$$

where,

EF = NO_x emission factor, ng of NO_x/J of fuel gas

$y\ (NO_x)$ = mole percent of NO_x expressed as an NO_2 equivalent

$M\ (NO_2)$ = molecular weight of NO_2

= 46.0055 kg/kmole

g_c = conversion factor

= 10^6

ΔH = gross heat value of the fuel gas, MJ/kmole

2.1.1.4 Results

(1) Basic Data:

Field Work

Date: October 7, 1985

Location: Sylvan Lake area

Test Crew: M. Towill

B. Reshetylo

Test Unit: Make - Superior White

Model - 86-825

Rated Power Level - 600 kW at 900 RPM

Service - Driver for a natural gas compressor

Ambient Temperature: 18°C

Barometric Pressure: 676 mm Hg

Relative Humidity: 67%

Lab Work

Date: October 21, 1985

Location: Calgary

Ambient Temperature: 21°C

Barometric Pressure: 658.8 mm Hg

(2) Gas Analysis:

Table 3. Flue gas composition: NO_x test report No. R-1.

Component	Mole Percent Sample 1	 Sample 2	 Representative* Composition
H_2	4.2810	2.0008	4.2810
Ar	0.9584	0.9280	0.9584
O_2	0.3595	7.7121	0.3595
N_2	80.1357	77.5898	80.1357
C_1	0.2070	0.1300	0.2070
CO	6.2204	2.9327	6.2204
CO_2	7.8135	8.6955	7.8135
C_2	0.0209	0.0097	0.0209
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0036	0.0014	0.0036
	100.0000	100.0000	100.0000

* The representative composition was taken to be that of sample 1. Sample 2 had an abnormally high O_2 concentration and therefore was suspect of air contamination.

Table 4. Fuel gas composition: NO_x test report No. R-1.

Component	Mole Percent
H_2	0.0000
Ar	0.0201
O_2	0.0000
N_2	1.6820
C_1	79.7729
CO	0.0000
CO_2	2.8188
C_2	9.6043
H_2S	0.0000
COS	0.0000
C_3	4.0671
SO_2	0.0000
CS_2	0.0000
$i\text{-}C_4$	0.5547
$n\text{-}C_4$	1.1536
$i\text{-}C_5$	0.1465
$n\text{-}C_5$	0.0715
C_6	0.0853
C_7+	0.0230
	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered - 0.1124 m^3

Meter Pressure - 675.9 mm Hg

Meter Temperature - 15.3°C

Impinger Pressure - 637.8 mm Hg

Moles of Dried Flue Gas Metered - 4.22 g - moles

Volume of H_2O Condensed - 13 ml

Moles of H_2O Condensed - 0.72 g - moles

Vapour Pressure of Drier - 6.774 mm Hg

Moles of H_2O Vapour - 0.05 g - moles

Total Moles of Wet Flue Gas - 4.99 g - moles

H_2O Concentration - 15.34 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 5. NO_x determination - field data: NO_x test report No. R-1.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
10	14:24	30	2080.7	53.70	678.54	18
6	14:27	30	2033.4	47.35	701.40	18
7	14:37	30	2073.5	47.35	696.32	18
35	15:27	30	2002.0	66.40	645.52	18
34	15:31	30	2003.0	53.70	683.62	18
30	15:33	30	2010.0	60.05	681.08	18

(b) Lab Data:

Table 6. NO_x determination - lab data: NO_x test report No. R-1.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
10	658.80	21	184.38
6	658.80	21	166.98
7	663.88	21	182.46
35	661.34	21	204.55
34	663.88	21	185.88
30	668.96	21	175.01

Representative NO_x Concentration**: 181.93 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 7. Overall gas compositions: NO_x test report No. R-1.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	15.3400
NO_x	0.0000	0.0000	0.0182
H_2	0.0000	4.2810	3.6235
Ar	0.0201	0.9584	0.8112
O_2	0.0000	0.3595	0.3043
N_2	1.6820	80.1357	67.8283
CO	0.0000	6.2204	5.2651
CO_2	2.8188	7.8135	6.6135
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
C_1	79.7729	0.2070	0.1752
C_2	9.6043	0.0209	0.0177
C_3	4.0671	0.0036	0.0030
i-C_4	0.5547	0.0000	0.0000
n-C_4	1.1538	0.0000	0.0000
i-C_5	0.1465	0.0000	0.0000
n-C_5	0.0715	0.0000	0.0000
C_6	0.0853	0.0000	0.0000
C_7+	0.0230	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 10.1335

Gross heating value of fuel gas = 42.84 MJ/m^3
= 1012 MJ/kmole

(c) NOx Emission Factor

Using equation (2), the NO_x emission factor is given by:

$$EF = \frac{0.01819 \cdot 10.1335 \cdot 46.0055 \cdot 10^6}{100 \cdot 1012}$$

$$= 83.8 \text{ ng/J}$$

The NO_x emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 94% less than this EPA number. This large difference is likely due to the rich fuel-air mixture which was used (i.e., insufficient air for stoichiometric combustion). This is evident in Table 7 where it can be seen that the overall flue gas composition contains significant concentrations of combustibles (i.e., H_2, CO, C_1, C_2 and C_3).

With rich fuel-air mixtures, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of NO_x.

2.1.1.5 Conclusions

The tested engine was not, from a thermodynamic point of view, operating at optimal conditions. The engine used a rich fuel-air mixture which has resulted in the relatively low NO_x emission factor of 83.8 ng/J.

2.1.2 Natural Gas Fueled Engines: NO_x Test Report No. R-2

Test Date: January 14, 1986
Test Location: Gilby area
Tested By: T. Seedhouse & C. Scott

2.1.2.1 Summary

A 820 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 2797 ng/J was obtained. This is approximately 89% higher than the value of 1481 ng/J (55 400 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

2.1.2.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

2.1.2.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

2.1.2.4 Results

(1) Basic Data:

Field Work

Date: January 14, 1986
Location: Gilby area
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Superior White
Model - 8GT-825
Rated Power Level - 820 kW at 900 RPM
Service - Driver for a natural gas compressor

Ambient Temperature: 12.0°C
Barometric Pressure: 669.29 mm Hg
Relative Humidity: 26%

Lab Work

Date: January 15, 1986
Location: Calgary
Ambient Temperature: 21.2°C
Barometric Pressure: 659.44 mm Hg

(2) Gas Analysis:

Table 8. Flue gas composition: NO_x test report No. R-2.

Component	Mole Percent Sample 1	Mole Percent Sample 2	Average Composition
H_2	0.0000	0.0000	0.0000
Ar	0.9942	0.9960	0.9951
O_2	7.4590	7.1327	7.2958
N_2	83.1257	83.2805	83.2030
C_1	0.3293	0.3313	0.3303
CO	0.0643	0.0638	0.0640
CO_2	7.9559	8.1473	8.0516
C_2	0.0332	0.0284	0.0308
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0135	0.0084	0.0110
iC_4	0.0107	0.0059	0.0083
nC_4	0.0099	0.0058	0.0079
iC_5	0.0012	0.0000	0.0006
nC_5	0.0033	0.0000	0.0016
	100.0000	100.0000	100.0000

Table 9: Fuel gas composition: NO_X test report No. R-2.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000
N_2	0.5703	0.5783	0.5743
C_1	82.3264	82.1873	82.2568
CO	0.0000	0.0000	0.0000
CO_2	4.4282	4.4733	4.4508
C_2	8.5449	8.5470	8.5459
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	2.8091	2.8832	2.8462
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
i-C_4	0.3702	0.3779	0.3741
n-C_4	0.6736	0.6907	0.6821
i-C_5	0.1235	0.1165	0.1200
n-C_5	0.1296	0.1181	0.1238
C_6+	0.0242	0.0278	0.0260
	100.0000	100.0000	100.0000

(3) Flué Gas Moisture Content

Volume of Flue Gas Metered - 0.1873 m^3
Meter Pressure - 669.29 mm Hg
Meter Temperature - 16.2°C
Impinger Pressure - 605.79 mm Hg
Moles of Dried Flue Gas Metered - 6.95 g - moles
Volume of H_2O Condensed - 10 ml
Moles of H_2O Condensed - 0.55 g - moles
Vapour Pressure of Drier - 8.905 mm Hg
Moles of H_2O Vapour - 0.10 g - moles
Total Moles of Wet Flue Gas - 7.61 g - moles
H_2O Concentration - 8.65 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 10. NO_x determination - field data: NO_x test report No. R-2.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
31	12:55	30	2011.0	48.26	669.29	10
8	12:58	30	2067.5	39.37	669.29	10
3	13:01	30	2054.3	39.37	669.29	10
33	13:41	30	2008.0	38.10	669.29	10
34	13:44	30	2003.0	36.83	666.75	10
6	13:46	30	2033.4	44.45	669.29	10

(b) Lab Data:

Table 11. NO_x determination - lab data: NO_x test report No. R-2.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
31	674.68	21	4342.65
8	674.68	21	3878.82
3	672.14	21	3835.73
33	674.68	21	3953.07
34	677.22	21	3841.17
6	674.68	21	3995.01

Representative NO_x Concentration**: 3917.02 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 12. Overall gas compositions: NO_x test report No. R-2.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	8.6500
NO_x	0.0000	0.0000	0.3917
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.9951	0.9051
O_2	0.0000	7.2958	6.6361
N_2	0.5743	83.2030	75.6800
CO	0.0000	0.0640	0.0582
CO_2	4.4508	8.0516	7.3236
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
C_1	82.2568	0.3303	0.3005
C_2	8.5459	0.0308	0.0280
C_3	2.8462	0.0110	0.0100
i-C_4	0.3741	0.0083	0.0076
n-C_4	0.6821	0.0079	0.0072
i-C_5	0.1200	0.0006	0.0005
n-C_5	0.1238	0.0016	0.0015
C_6	0.0260	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 15.0484

Gross heating value of fuel gas = 41.02 MJ/m^3
= 969 MJ/kmole

(c) NO_x Emission Factor

Using equation (2), the NO_x emission factor is given by:

$$EF = \frac{0.3917 \cdot 15.0484 \cdot 46.0055 \cdot 10^6}{100 \cdot 969}$$

$$= 2797 \text{ ng/J}$$

The NO_x emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 89% higher than this EPA number.

2.1.2.5 Conclusions

The NO_x emission factor for the tested reciprocating engine is 2797 ng/J.

2.1.3 Natural Gas Fueled Engines: NO_x Test Report No. R-3

Test Date: January 16, 1986
Test Location: Sylvan Lake Area
Tested By: C. Scott & B. Reshetylo

2.1.3.1 Summary

A 600 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 147.6 ng/J was obtained. This is approximately 90% lower than the value of 1481 ng/J (55 400 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines. The significantly lower emission factor which has been obtained here is likely due to the rich fuel-air mixture (i.e., insufficient air for stoichiometric combustion) on which the engine operated. With such a fuel mixture, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of NO_x.

2.1.3.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

2.1.3.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

2.1.3.4 Results

(1) Basic Data:

Field Work

Date: January 16, 1986
Location: Sylvan Lake Area
Test Crew: C. Scott & B. Reshetylo

Test Unit: Make - Superior White
Model - 86-825
Rated Power Level - 600 kW at 900 RPM
Service - Driver for a natural gas compressor

Ambient Temperature: 3°C
Barometric Pressure: 644.2 mm Hg
Relative Humidity: 39%

Lab Work

Date: January 22, 1986
Location: Calgary
Ambient Temperature: 21.5°C
Barometric Pressure: 660.54 mm Hg

(2) Gas Analysis:

Table 13. Flue gas composition: NO_x test report No. R-3.

Component	Mole Percent Sample 1	 Sample 2	 Average
H_2	2.5192	2.5294	2.5243
Ar	0.9729	0.9717	0.9723
O_2	0.2256	0.2159	0.2208
N_2	81.3501	81.2445	81.2973
C_1	0.1130	0.1116	0.1123
CO	4.9057	4.9044	4.9050
CO_2	9.8754	9.9978	9.9366
C_2	0.0191	0.0194	0.0192
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0041	0.0040	0.0041
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
iC_4	0.0127	0.0003	0.0065
nC_4	0.0022	0.0010	0.0016
	100.0000	100.0000	100.0000

Table 14. Fuel gas composition: NO_x test report No. R-3.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000
N_2	0.7091	0.6365	0.6728
C_1	77.9237	78.3689	78.1463
CO	0.0000	0.0000	0.0000
CO_2	3.0773	3.0365	3.0569
C_2	10.8775	10.8163	10.8469
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	4.5590	4.4743	4.5166
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
i-C_4	0.7130	0.6897	0.7014
n-C_4	1.3239	1.2606	1.2923
i-C_5	0.3075	0.2658	0.2866
n-C_5	0.3155	0.2689	0.2922
C_6	0.1529	0.1447	0.1488
C_7+	0.0406	0.0378	0.0392
	100.0000	100.0000	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.2306 m^3
Meter Pressure -	664.21 mm Hg
Meter Temperature -	18.3°C
Impinger Pressure -	600.71 mm Hg
Moles of Dried Flue Gas Metered -	8.43 g - moles
Volume of H_2O Condensed -	27 ml
Moles of H_2O Condensed -	1.50 g - moles
Vapour Pressure of Drier -	6.916 mm Hg
Moles of H_2O Vapour -	0.10 g - moles
Total Moles of Wet Flue Gas -	10.02 g - moles
H_2O Concentration -	15.91 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 15. NO_x determination - field data: NO_x test report No. R-3.

Flask Number	Time	Volume (ml) Absorbing Solution	Volume (ml) Flask	Flask Pressure (mm Hg) Evacuated	Flask Pressure (mm Hg) Filled	Flask Temperature (°C)
9	13:10	30	2038.4	36.83	664.21	3
6	13:12	30	2033.4	40.64	664.21	3
34	13:16	30	2003.0	41.91	664.21	3
23	13:48	30	1992.7	41.91	664.21	3
27	13:50	30	2020.0	43.18	664.21	3
22	13:53	30	2024.7	44.45	664.21	3

(b) Lab Data:

Table 16. NO_x determination - lab data: NO_x test report No. R-3.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
9	680.86	21.5	357.66
6	660.54	21.5	395.90
34	660.54	21.5	432.60
23	693.56	21.5	261.82
27	693.56	21.5	253.00
22	660.54	21.5	312.57

Representative NO_x Concentration**: 331.99 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 17. Overall gas compositions: NO_x test report No. R-3.

Component	Composition (mole percent) Fuel Gas	 H_2O & NO_x Free Flue Gas	 Flue Gas
H_2O	0.0000	0.0000	15.9100
NO_x	0.0000	0.0000	0.0332
H_2	0.0000	2.5243	2.1218
Ar	0.0000	0.9723	0.8173
O_2	0.0000	0.2208	0.1856
N_2	0.6728	81.2973	68.3360
CO	0.0000	4.9050	4.1230
CO_2	3.0569	9.9366	8.3524
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
C_1	78.1463	0.1123	0.0944
C_2	10.8469	0.0192	0.0161
C_3	4.5166	0.0041	0.0034
i-C_4	0.7014	0.0065	0.0055
n-C_4	1.2923	0.0016	0.0013
i-C_5	0.2866	0.0000	0.0000
n-C_5	0.2922	0.0000	0.0000
C_6	0.1488	0.0000	0.0000
C_7+	0.0392	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 10.1651

Gross heating value of fuel gas = 44.50 MJ/m^3
= 1052 MJ/kmole

(c) NOx Emission Factor

Using equation (2), the NO_x emission factor is given by:

$$EF = \frac{0.033199 \cdot 10.1651 \cdot 46.0055 \cdot 10^6}{100 \cdot 1052}$$

$$= 147.6 \text{ ng/J}$$

The NO_x emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 90% less than this EPA number. This large difference is likely due to the rich fuel-air mixture which was used (i.e., insufficient air for stoichiometric combustion). This is evident in Table 17 where it can be seen that the overall flue gas composition contains significant concentrations of combustibles (i.e., H_2, CO, C_1, C_2, C_3, i-C_4 and n-C_4).

With rich fuel-air mixtures, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of NO_x.

2.1.3.5 Conclusion

The tested engine was not, from a thermodynamic point of view, operating at optimal conditions. The engine used a rich fuel-air mixture which has resulted in the relatively low NO_x emission factor of 147.6 ng/J.

2.1.4 Natural Gas Fueled Engines: NO_x Test Report No. R-4

Test Date: January 16, 1986
Test Location: Sylvan Lake Area
Tested By: C. Scott & B. Reshetylo

2.1.4.1 Summary

A 895 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 83.3 ng/J was obtained. This is approximately 94% lower than the value of 1481 ng/J (55 400 $kg/10^6$ $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines. The significantly lower emission factor which has been obtained here is likely due to the rich fuel-air mixture (i.e., insufficient air for stoichiometric combustion) on which the engine operated. With such a fuel mixture, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of NO_x.

2.1.4.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

2.1.4.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

2.1.4.4 Results

(1) Basic Data:

Field Work

Date: January 16, 1986
Location: Sylvan Lake Area
Test Crew: C. Scott
B. Reshetylo

Test Unit: Make - Superior White
Model - 12G-825
Rated Power Level - 895 kW at 900 RPM
Service - Driver for a natural gas compressor

Ambient Temperature: 13°C
Barometric Pressure: 664.2 mm Hg
Relative Humidity: 39%

Lab Work

Date: January 22, 1986
Location: Calgary
Ambient Temperature: 21.5°C
Barometric Pressure: 660.54 mm Hg

(2) Gas Analysis:

Table 18. Flue gas composition: NO_x test report No. R-4.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	3.0695	3.0713	3.0704
Ar	0.9667	0.9670	0.9668
O_2	0.1644	0.1697	0.1671
N_2	80.8285	80.8565	80.8425
C_1	0.0409	0.0474	0.0442
CO	5.4586	5.4231	5.4408
CO_2	9.4477	9.4404	9.4441
C_2	0.0162	0.0167	0.0164
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0038	0.0054	0.0046
SO_2	0.0020	0.0019	0.0020
CS_2	0.0000	0.0000	0.0000
i-C_4	0.0006	0.0002	0.0004
n-C_4	0.0011	0.0004	0.0007
	100.0000	100.0000	100.0000

Table 19. Fuel gas composition: NO_x test report No. R-4.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000
N_2	0.6354	0.7454	0.6904
C_1	78.7357	78.1897	78.4627
CO	0.0000	0.0000	0.0000
CO_2	3.1345	3.1950	3.1647
C_2	10.6944	10.7851	10.7398
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	4.3583	4.4502	4.4042
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
$i\text{-}C_4$	0.6595	0.6776	0.6686
$n\text{-}C_4$	1.1849	1.2597	1.2223
$i\text{-}C_5$	0.2408	0.2745	0.2577
$n\text{-}C_5$	0.2348	0.2696	0.2522
C_6	0.1079	0.1322	0.1200
C_7+	0.0138	0.0210	0.0174
	100.0000	100.0000	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.2304 m^3
Meter Pressure -	664.21 mm Hg
Meter Temperature -	14.4°C
Impinger Pressure -	600.71 mm Hg
Moles of Dried Flue Gas Metered -	8.53 g - moles
Volume of H_2O Condensed -	30 ml
Moles of H_2O Condensed -	1.66 g - moles
Vapour Pressure of Drier -	6.774 mm Hg
Moles of H_2O Vapour -	0.10 g - moles
Total Moles of Wet Flue Gas -	10.29 g - moles
H_2O Concentration -	17.09 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 20. NO_x determination - field data: NO_x test report No. R-4.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
35	12:02	30	2002.0	33.01	664.21	3
3	12:05	30	2054.3	30.47	664.21	3
8	12:07	30	2067.5	31.74	664.21	3
17	12:42	30	2102.8	31.74	664.21	3
18	12:44	30	2041.2	34.28	664.21	3
33	12:47	30	2008.0	36.82	664.21	3

(b) Lab Data:

Table 21. NO_x determination - lab data: NO_x test report No. R-4.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
35	673.24	21.5	183.07
3	660.54	21.5	195.80
8	683.40	21.5	179.18
17	660.54	21.5	180.74
18	660.54	21.5	163.94
33	685.94	21.5	193.99

Representative NO_x Concentration**: 184.25 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 22. Overall gas compositions: NO_x test report No. R-4.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	17.0900
NO_x	0.0000	0.0000	0.0184
H_2	0.0000	3.0704	2.5451
Ar	0.0000	0.9668	0.8014
O_2	0.0000	0.1671	0.1385
N_2	0.6904	80.8425	67.0116
CO	0.0000	5.4408	4.5100
CO_2	3.1647	9.4441	7.8284
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0020	0.0017
CS_2	0.0000	0.0000	0.0000
C_1	78.4627	0.0442	0.0366
C_2	10.7398	0.0164	0.0136
C_3	4.4042	0.0046	0.0038
i-C_4	0.6686	0.0004	0.0003
n-C_4	1.2223	0.0007	0.0006
i-C_5	0.2577	0.0000	0.0000
n-C_5	0.2522	0.0000	0.0000
C_6	0.1200	0.0000	0.0000
C_7+	0.0174	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 10.2498

Gross heating value of fuel gas = 44.12 MJ/m^3
= 1043 MJ/kmole

(c) NOx Emission Factor

Using equation (2), the NO_x emission factor is given by:

$$EF = \frac{0.018425 \cdot 10.2498 . 46.0055 \cdot 10^6}{100 \cdot 1043}$$

$$= 83.3 \text{ ng/J}$$

The NO_x emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 94% less than this EPA number. This large difference is likely due to the rich fuel-air mixture which was used (i.e., insufficient air for stoichiometric combustion). This is evident in Table 22 where it can be seen that the overall flue gas composition contains significant concentrations of combustibles (i.e., H_2, CO, C_1, C_2, C_3, i-C_4 and n-C_4).

With rich fuel-air mixtures, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of NO_x.

2.1.4.5 Conclusions

The tested engine was not, from a thermodynamic point of view, operating at optimal conditions. The engine used a rich fuel-air mixture which has resulted in the relatively low NO_x emission factor of 83.3 ng/J.

2.1.5 Natural Gas Fueled Engines: NO_x Test Report No. R-5

Test Date: January 16, 1986
Test Location: Sylvan Lake Area
Tested By: C. Scott & B. Reshetylo

2.1.5.1 Summary

A 480 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 323.1 ng/J was obtained. This is approximately 78% lower than the value of 1481 ng/J (55 400 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines. The significantly lower emission factor which has been obtained here is likely due to the rich fuel-air mixture (i.e., insufficient air for stoichiometric combustion) on which the engine operated. With such a fuel mixture, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of NO_x.

2.1.5.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

2.1.5.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

2.1.5.4 Results

(1) Basic Data:

Field Work

Date: January 16, 1986
Location: Sylvan Lake Area
Test Crew: C. Scott
B. Reshetylo

Test Unit: Make - Waukesha
Model - L-3711
Rated Power Level - 480 kW @ 1200 RPM
Service - Driver for a natural gas compressor

Ambient Temperature: 20°C
Barometric Pressure: 664.2 mm Hg
Relative Humidity: 39%

Lab Work

Date: January 22, 1986
Location: Calgary
Ambient Temperature: 21.5°C
Barometric Pressure: 660.54 mm Hg

(2) Gas Analysis:

Table 23. Flue gas composition: NO_x test report No. R-5.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	1.8130	1.6634	1.7382
Ar	0.9906	0.9897	0.9901
O_2	0.2001	0.2126	0.2063
N_2	82.8240	82.7484	82.7862
C_1	0.0717	0.1051	0.0884
CO	3.3337	3.3087	3.3212
CO_2	10.7482	10.9469	10.8476
C_2	0.0144	0.0150	0.0147
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0016	0.0016	0.0016
SO_2	0.0027	0.0086	0.0057
CS_2	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

Table 24. Fuel gas composition: NO_x test report No. R-5.

Component	Mole Percent Sample 1	 Sample 2	 Average
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000
N_2	0.6389	0.6057	0.6223
C_1	83.1210	83.2397	83.1804
CO	0.0000	0.0000	0.0000
CO_2	3.4805	3.4403	3.4604
C_2	10.9433	10.8837	10.9135
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	1.7866	1.8047	1.7956
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
i-C_4	0.0119	0.0119	0.0119
n-C_4	0.0178	0.0140	0.0159
i-C_5	0.0000	0.0000	0.0000
n-C_5	0.0000	0.0000	0.0000
C_6	0.0000	0.0000	0.0000
C_7+	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.2063 m^3
Meter Pressure -	664.20 mm Hg
Meter Temperature -	8.3°C
Impinger Pressure -	600.70 mm Hg
Moles of Dried Flue Gas Metered -	7.81 g - moles
Volume of H_2O Condensed -	26 ml
Moles of H_2O Condensed -	1.44 g - moles
Vapour Pressure of Drier -	7.160 mm Hg
Moles of H_2O Vapour -	0.09 g - moles
Total Moles of Wet Flue Gas -	9.34 g - moles
H_2O Concentration -	16.43 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 25. NO_x determination - field data: NO_x test report No. R-5.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
5	10:44	30	2041.5	34.28	664.20	5
2	10:47	30	2105.2	43.17	664.20	5
15	10:49	30	2027.3	41.90	661.66	5
20	11:31	30	2079.9	43.17	664.20	5
12	11:33	30	2032.0	36.82	661.66	5
10	11:35	30	2080.7	39.36	664.20	5

(b) Lab Data:

Table 26. NO_x determination - lab data: NO_x test report No. R-5.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
5	683.40	21.5	732.13
2	663.08	21.5	599.68
15	579.26	21.5	262.77
20	660.54	21.5	760.32
12	660.54	21.5	708.17
10	660.54	21.5	789.99

Representative NO_x Concentration**: 700.08 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 27. Overall gas compositions: NO_x test report No. R-5.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	16.4300
NO_x	0.0000	0.0000	0.0700
H_2	0.0000	1.7382	1.4514
Ar	0.0000	0.9901	0.8267
O_2	0.0000	0.2063	0.1723
N_2	0.6223	82.7862	69.1265
CO	0.0000	3.3212	2.7732
CO_2	3.4604	10.8476	9.0577
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0057	0.0048
CS_2	0.0000	0.0000	0.0000
C_1	83.1804	0.0884	0.0738
C_2	10.9135	0.0147	0.0123
C_3	1.7956	0.0016	0.0013
i-C_4	0.0119	0.0000	0.0000
n-C_4	0.0159	0.0000	0.0000
i-C_5	0.0000	0.0000	0.0000
n-C_5	0.0000	0.0000	0.0000
C_6	0.0000	0.0000	0.0000
C_7+	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 9.5502

Gross heating value of fuel gas = 40.28 MJ/m^3
= 952 MJ/kmole

(c) NO_x Emission Factor

Using equation (2), the NOx emission factor is given by:

$$EF = \frac{0.070008 \cdot 9.5502 \cdot 46.0055 \cdot 10^6}{100 \cdot 952}$$

$$= 323.1 \text{ ng/J}$$

The NO_x emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 78% less than this EPA number. This large difference is likely due to the rich fuel-air mixture which was used (i.e., insufficient air for stoichiometric combustion). This is evident in Table 27 where it can be seen that the overall flue gas composition contains significant concentrations of combustibles (i.e., H_2, CO, C_1, C_2 and C_3).

With rich fuel-air mixtures, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of NO_x.

2.1.5.5 Conclusions

The tested engine was not, from a thermodynamic point of view, operating at optimal conditions. The engine used a rich fuel-air mixture which has resulted in the relatively low NO_x emission factor of 323.1 ng/J.

2.1.6 Natural Gas Fueled Engines: NO_x Test Report No. R-6

Test Date: February 24, 1986
Test Location: Moose Mountain
Tested By: T. Seedhouse & C. Scott

2.1.6.1 Summary

A 1200 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 715 ng/J was obtained. This is approximately 52% lower than the value of 1481 ng/J (55 400 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

2.1.6.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

2.1.6.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

2.1.6.4 Results

(1) Basic Data:

Field Work

Date: February 24, 1986
Location: Moose Mountain
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Superior White
Model - 16-C825
Rated Power Level - 1200 kW at 900 RPM
Service - Driver for a natural gas compressor

Ambient Temperature: 8.0°C
Barometric Pressure: 670.56 mm Hg
Relative Humidity: 53%

Lab Work

Date: February 26, 1986
Location: Calgary
Ambient Temperature: 21.5°C
Barometric Pressure: 674.40 mm Hg

(2) Gas Analysis:

Table 28. Flue gas composition: NO_x test report No. R-6.

Component	Mole Percent Sample 1	Sample 2	Average Composition
H_2	0.4664	0.4468	0.4566
Ar	1.0234	1.0236	1.0235
O_2	0.1037	0.0567	0.0802
N_2	85.5715	85.5821	85.5768
C_1	0.0700	0.0709	0.0704
CO	0.6862	0.6912	0.6887
CO_2	12.0712	12.1162	12.0937
C_2	0.0057	0.0049	0.0053
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0000	0.0000	0.0000
SO_2	0.0019	0.0076	0.0048
CS_2	0.0000	0.0000	0.0000
iC_4	0.0000	0.0000	0.0000
nC_4	0.0000	0.0000	0.0000
iC_5	0.0000	0.0000	0.0000
nC_5	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

Table 29. Fuel gas composition: NO_x test report No. R-6.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000
N_2	0.6380	0.6157	0.6269
C_1	91.0040	90.9166	90.9603
CO	0.0000	0.0000	0.0000
CO_2	0.0000	0.0000	0.0000
C_2	7.5861	7.6733	7.6297
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.7559	0.7780	0.7669
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
$i\text{-}C_4$	0.0049	0.0044	0.0046
$n\text{-}C_4$	0.0055	0.0060	0.0058
$i\text{-}C_5$	0.0023	0.0026	0.0024
$n\text{-}C_5$	0.0033	0.0034	0.0034
C_6+	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.2065 m^3
Meter Pressure -	670.56 mm Hg
Meter Temperature -	15.8°C
Impinger Pressure -	613.41 mm Hg
Moles of Dried Flue Gas Metered -	7.68 g - moles
Volume of H_2O Condensed -	29 ml
Moles of H_2O Condensed -	1.61 g - moles
Vapour Pressure of Drier -	6.015 mm Hg
Moles of H_2O Vapour -	0.08 g - moles
Total Moles of Wet Flue Gas -	9.37 g - moles
H_2O Concentration -	17.96 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 30. NO_x determination - field data: NO_x test report No. R-6.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
6	11:46	30	2033.4	58.42	670.56	8
7	11:49	30	2073.5	62.23	670.56	8
9	12:23	30	2038.4	63.50	670.56	8
34	12:27	30	2003.0	68.58	670.56	8

(b) Lab Data:

Table 31. NO_x determination - lab data: NO_x test report No. R-6.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
6	641.38	21.5	1559.33
7	628.68	21.5	1285.28
9	643.92	21.5	1428.48
34	633.76	21.5	1441.10

Average NO_x Concentration: 1428.55 ppm

* On a wet basis.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 32. Overall gas compositions: NO_x test report No. R-6.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	17.9600
NO_x	0.0000	0.0000	0.1429
H_2	0.0000	0.4566	0.3739
Ar	0.0000	1.0235	0.8382
O_2	0.0000	0.0802	0.0657
N_2	0.6269	85.5768	70.0850
CO	0.0000	0.6887	0.5640
CO_2	0.0000	12.0937	9.9044
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0048	0.0039
CS_2	0.0000	0.0000	0.0000
C_1	90.9603	0.0704	0.0577
C_2	7.6297	0.0053	0.0043
C_3	0.7669	0.0000	0.0000
$i-C_4$	0.0046	0.0000	0.0000
$n-C_4$	0.0058	0.0000	0.0000
$i-C_5$	0.0024	0.0000	0.0000
$n-C_5$	0.0034	0.0000	0.0000
C_6	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 10.3079

Gross heating value of fuel gas = 40.07 MJ/m^3
= 947 MJ/kmole

(c) NOx Emission Factor

Using equation (2), the NO_x emission factor is given by:

$$EF = \frac{0.1429 \cdot 10.3079 \cdot 46.0055 \cdot 10^6}{100 \cdot 947}$$

$$= 715 \text{ ng/J}$$

The NO_x emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 52% lower than this EPA number.

2.1.6.5 Conclusions

The NO_x emission factor for the tested reciprocating engine is 715 ng/J.

2.1.7 Natural Gas Fueled Engines: NO_x Test Report No. R-7

Test Date: February 25, 1986
Test Location: Crossfield - North
Tested By: T. Seedhouse & C. Scott

2.1.7.1 Summary

A 1500 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 719 ng/J was obtained. This is approximately 51% lower than the value of 1481 ng/J (55 400 kg/10^6 Nm^3 of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

2.1.7.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

2.1.7.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

2.1.7.4 Results

(1) Basic Data:

Field Work

Date: February 25, 1986
Location: Crossfield - North
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Deleval
Model - HT 80-2
Rated Power Level - 1500 kW at 600 RPM
Service - Driver for a natural gas compressor

Ambient Temperature: 6.0°C
Barometric Pressure: 671.58 mm Hg
Relative Humidity: 44%

Lab Work

Date: February 26, 1986
Location: Calgary
Ambient Temperature: 21.5°C
Barometric Pressure: 674.40 mm Hg

(2) Gas Analysis:

Table 33. Flue gas composition: NO_x test report No. R-7.

Component	Mole Percent Sample 1	 Sample 2	 Average Composition
H_2	0.0000	0.0000	0.0000
Ar	0.9764	0.9799	0.9781
O_2	11.6067	11.0016	11.3042
N_2	81.6418	81.9291	81.7855
C_1	0.2233	0.2567	0.2400
CO	0.0289	0.0319	0.0304
CO_2	5.4942	5.7798	5.6370
C_2	0.0213	0.0182	0.0197
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0000	0.0000	0.0000
SO_2	0.0074	0.0028	0.0051
CS_2	0.0000	0.0000	0.0000
iC_4	0.0000	0.0000	0.0000
nC_4	0.0000	0.0000	0.0000
iC_5	0.0000	0.0000	0.0000
nC_5	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

Table 34. Fuel gas composition: NO_x test report No. R-7.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000
N_2	0.7675	0.5120	0.6398
C_1	89.4824	90.1686	89.8255
CO	0.0000	0.0000	0.0000
CO_2	0.1085	0.0793	0.0939
C_2	9.2578	8.9558	9.1068
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.3838	0.2843	0.3340
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
$i-C_4$	0.0000	0.0000	0.0000
$n-C_4$	0.0000	0.0000	0.0000
$i-C_5$	0.0000	0.0000	0.0000
$n-C_5$	0.0000	0.0000	0.0000
C_6+	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.2616 m^3
Meter Pressure -	671.58 mm Hg
Meter Temperature -	19.7°C
Impinger Pressure -	608.08 mm Hg
Moles of Dried Flue Gas Metered -	9.62 g - moles
Volume of H_2O Condensed -	14 ml
Moles of H_2O Condensed -	0.78 g - moles
Vapour Pressure of Drier -	5.685 mm Hg
Moles of H_2O Vapour -	0.09 g - moles
Total Moles of Wet Flue Gas -	10.49 g - moles
H_2O Concentration -	8.26 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 35. NO_x determination - field data: NO_x test report No. R-7.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
15	10:17	30	2027.3	69.60	671.58	6
8	10:24	30	2067.5	75.95	671.58	6
18	10:27	30	2041.2	64.52	671.58	6
2	11:15	30	2105.2	69.60	671.58	6
5	11:18	30	2041.5	61.98	671.58	6
20	11:22	30	2079.9	64.52	671.58	6

(b) Lab Data:

Table 36. NO_x determination - lab data: NO_x test report No. R-7.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
15	738.15	21.5	688.02
8	775.24	21.5	1102.35
18	743.74	21.5	736.58
2	754.41	21.5	824.07
5	730.79	21.5	616.83
20	742.47	21.5	715.43

Representative NO_x Concentration**: 741.03 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 37. Overall gas compositions: NO_x test report No. R-7.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	8.2600
NO_x	0.0000	0.0000	0.0741
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.9781	0.8966
O_2	0.0000	11.3042	10.3621
N_2	0.6398	81.7855	74.9694
CO	0.0000	0.0304	0.0279
CO_2	0.0939	5.6370	5.1672
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0051	0.0047
CS_2	0.0000	0.0000	0.0000
C_1	89.8255	0.2400	0.2200
C_2	9.1068	0.0197	0.0181
C_3	0.3340	0.0000	0.0000
i-C_4	0.0000	0.0000	0.0000
n-C_4	0.0000	0.0000	0.0000
i-C_5	0.0000	0.0000	0.0000
n-C_5	0.0000	0.0000	0.0000
C_6	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 20.0204

Gross heating value of fuel gas = 41.19 MJ/m^3
= 950 MJ/kmole

(c) NO$_x$ Emission Factor

Using equation (2), the NO$_x$ emission factor is given by:

$$EF = \frac{0.0741 \cdot 20.0204 \cdot 46.0055 \cdot 10^6}{100 \cdot 950}$$

$$= 719 \text{ ng/J}$$

The NO$_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 51% lower than this EPA number.

2.1.7.5 Conclusions

The NO$_x$ emission factor for the tested reciprocating engine is 719 ng/J.

2.1.8 Natural Gas Fueled Engines: NO_x Test Report No. R-8

Test Date: February 25, 1986
Test Location: Crossfield - South
Tested By: T. Seedhouse & C. Scott

2.1.8.1 Summary

A 820 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 218 ng/J was obtained. This is approximately 85% lower than the value of 1481 ng/J (55 400 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

2.1.8.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

2.1.8.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

2.1.8.4 Results

(1) Basic Data:

Field Work

Date: February 25, 1986
Location: Crossfield - South
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Cooper Bessemer
Model - GMVA-8
Rated Power Level - 820 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 7.0°C
Barometric Pressure: 671.58 mm Hg
Relative Humidity: 44%

Lab Work

Date: February 26, 1986
Location: Calgary
Ambient Temperature: 21.5°C
Barometric Pressure: 674.40 mm Hg

(2) Gas Analysis:

Table 38. Flue gas composition: NO_x test report No. R-8.

Component	Mole Percent Sample 1	Sample 2	Average Composition
H_2	0.0000	0.0000	0.0000
Ar	0.9569	0.9572	0.9570
O_2	15.8307	15.8454	15.8381
N_2	80.0088	80.0377	80.0232
C_1	0.2928	0.2810	0.2869
CO	0.0087	0.0091	0.0089
CO_2	2.8741	2.8431	2.8586
C_2	0.0265	0.0250	0.0258
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0015	0.0015	0.0015
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
iC_4	0.0000	0.0000	0.0000
nC_4	0.0000	0.0000	0.0000
iC_5	0.0000	0.0000	0.0000
nC_5	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

Table 39. Fuel gas composition: NO_x test report No. R-8.

Component	Mole Percent
H_2	0.0000
Ar	0.0000
O_2	0.0000
N_2	0.4684
C_1	89.7300
CO	0.0000
CO_2	0.0668
C_2	9.2234
H_2S	0.0000
COS	0.0000
C_3	0.5103
SO_2	0.0000
CS_2	0.0000
i-C_4	0.0007
n-C_4	0.0004
i-C_5	0.0000
n-C_5	0.0000
C_6+	0.0000
	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.2022 m^3
Meter Pressure -	671.58 mm Hg
Meter Temperature -	18.5°C
Impinger Pressure -	608.08 mm Hg
Moles of Dried Flue Gas Metered -	7.47 g - moles
Volume of H_2O Condensed -	5 ml
Moles of H_2O Condensed -	0.28 g - moles
Vapour Pressure of Drier -	5.806 mm Hg
Moles of H_2O Vapour -	0.07 g - moles
Total Moles of Wet Flue Gas -	7.82 g - moles
H_2O Concentration -	4.46 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 40. NO_x determination - field data: NO_x test report No. R-8.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
32	12:33	30	2004.0	67.06	671.58	7
35	12:36	30	2002.0	74.68	671.58	7
33	12:39	30	2008.0	81.03	671.58	7
10	13:23	30	2080.7	72.14	674.12	7
17	13:27	30	2102.8	73.41	671.58	7
12	13:30	30	2032.0	77.22	671.58	7

(b) Lab Data:

Table 41. NO_x determination - lab data: NO_x test report No. R-8.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
32	669.32	21.5	92.47
35	659.16	21.5	201.09
33	671.86	21.5	143.31
10	674.40	21.5	120.59
17	674.40	21.5	111.28
12	674.40	21.5	130.13

Representative NO_x Concentration**: 126.33 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 42. Overall Gas Compositions: NO_x test report No. R-8.

Component	Composition (mole percent) Fuel Gas	Composition (mole percent) H_2O & NO_x Free Flue Gas	Composition (mole percent) Flue Gas
H_2O	0.0000	0.0000	4.4600
NO_x	0.0000	0.0000	0.0126
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.9570	0.9142
O_2	0.0000	15.8381	15.1297
N_2	0.4684	80.0232	76.4441
CO	0.0000	0.0089	0.0085
CO_2	0.0668	2.8586	2.7308
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
C_1	89.7300	0.2869	0.2741
C_2	9.2234	0.0258	0.0246
C_3	0.5103	0.0015	0.0014
i-C_4	0.0007	0.0000	0.0000
n-C_4	0.0004	0.0000	0.0000
i-C_5	0.0000	0.0000	0.0000
n-C_5	0.0000	0.0000	0.0000
C_6	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 35.79

Gross heating value of fuel gas = 40.39 MJ/m^3
= 955 MJ/kmole

(c) NOx Emission Factor

Using equation (2), the NO$_x$ emission factor is given by:

$$EF = \frac{0.0126 \cdot 35.79 \cdot 46.0055 \cdot 10^6}{100 \cdot 955}$$

$$= 218 \text{ ng/J}$$

The NO$_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 85% lower than this EPA number.

2.1.8.5 Conclusions

The NO$_x$ emission factor for the tested reciprocating engine is 218 ng/J.

2.1.9 Natural Gas Fueled Engines: NO_x Test Report No. R-9

Test Date: February 27, 1986
Test Location: Harmatten Area
Tested By: T. Seedhouse & C. Scott

2.1.9.1 Summary

A 930 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 3412 ng/J was obtained. This is approximately 130% higher than the value of 1481 ng/J (55 400 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

2.1.9.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

2.1.9.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

2.1.9.4 Results

(1) Basic Data:

Field Work

Date: February 27, 1986
Location: Harmatten Area
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Ingersol Rand
Model - kVS (Turbo)
Rated Power Level - 930 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 6.0°C
Barometric Pressure: 664.97 mm Hg
Relative Humidity: 34%

Lab Work

Date: March 3, 1986
Location: Calgary
Ambient Temperature: 21.0°C
Barometric Pressure: 674.50 mm Hg

(2) Gas Analysis:

Table 43. Flue gas composition: NO_x test report No. R-9.

Component	Mole Percent Sample 1	Sample 2	Average Composition
H_2	0.0000	0.0000	0.0000
Ar	0.9705	0.9773	0.9739
O_2	12.4387	12.0597	12.2492
N_2	81.1421	81.7128	81.4275
C_1	0.2209	0.0326	0.1267
CO	0.0165	0.0175	0.0170
CO_2	5.1869	5.2001	5.1935
C_2	0.0232	0.0000	0.0116
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0012	0.0000	0.0006
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
iC_4	0.0000	0.0000	0.0000
nC_4	0.0000	0.0000	0.0000
iC_5	0.0000	0.0000	0.0000
nC_5	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

Table 44. Fuel gas composition: NO_x test report No. R-9.

Component	Mole Percent
H_2	0.0000
Ar	0.0000
O_2	0.0000
N_2	0.0892
C_1	68.1466
CO	0.0000
CO_2	6.9032
C_2	23.6125
H_2S	0.0000
COS	0.0000
C_3	1.2307
SO_2	0.0000
CS_2	0.0000
$i-C_4$	0.0051
$n-C_4$	0.0036
$i-C_5$	0.0052
$n-C_5$	0.0039
C_6+	0.0000
	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.1546 m^3
Meter Pressure -	664.97 mm Hg
Meter Temperature -	9.1°C
Impinger Pressure -	614.17 mm Hg
Moles of Dried Flue Gas Metered -	5.84 g - moles
Volume of H_2O Condensed -	10 ml
Moles of H_2O Condensed -	0.55 g - moles
Vapour Pressure of Drier -	6.231 mm Hg
Moles of H_2O Vapour -	0.06 g - moles
Total Moles of Wet Flue Gas -	6.46 g - moles
H_2O Concentration -	9.51 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 45. NO_x determination - field data: NO_x test report No. R-9.

Flask Number	Time	Volume (ml) Absorbing Solution	Volume (ml) Flask	Flask Pressure (mm Hg) Evacuated	Flask Pressure (mm Hg) Filled	Flask Temperature (°C)
26	10:51	30	2020.0	69.37	664.97	6
27	10:54	30	2020.0	68.10	667.47	6
22	10:57	30	2024.7	68.10	664.97	6
30	11:36	30	2010.0	65.56	664.97	6
28	11:40	30	2001.0	60.48	664.97	6
23	11:43	30	1992.7	68.10	664.97	6

(b) Lab Data:

Table 46. NO_x determination - lab data: NO_x test report No. R-9.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
26	684.66	21.0	3059.33
27	674.50	21.0	2778.37
22	677.04	21.0	2949.89
30	674.50	21.0	3038.55
28	692.28	21.0	2657.34
23	684.66	21.0	2187.92

Representative NO_x Concentration**: 2856.04 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 47. Overall gas compositions: NO_x test report No. R-9.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	9.5100
NO_x	0.0000	0.0000	0.2856
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.9739	0.8785
O_2	0.0000	12.2492	11.0493
N_2	0.0892	81.4275	73.4512
CO	0.0000	0.0170	0.0153
CO_2	6.9032	5.1935	4.6847
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
C_1	68.1466	0.1267	0.1143
C_2	23.6125	0.0116	0.0105
C_3	1.2307	0.0006	0.0005
i-C_4	0.0051	0.0000	0.0000
n-C_4	0.0036	0.0000	0.0000
i-C_5	0.0052	0.0000	0.0000
n-C_5	0.0039	0.0000	0.0000
C_6	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 26.0593

Gross heating value of fuel gas = 42.46 MJ/m^3
= 1003 MJ/kmole

(c) NO$_x$ Emission Factor

Using equation (2), the NO$_x$ emission factor is given by:

$$EF = \frac{0.2856 \cdot 26.0593 \cdot 46.0055 \cdot 10^6}{100 \cdot 1003}$$

$$= 3412 \text{ ng/J}$$

The NO$_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 130% higher than this EPA number.

2.1.9.5 Conclusions

The NO$_x$ emission factor for the tested reciprocating engine is 3412 ng/J.

2.1.10 Natural Gas Fueled Engines: NO_x Test Report No. R-10

Test Date: February 27, 1986
Test Location: Harmatten Area
Tested By: T. Seedhouse & C. Scott

2.1.10.1 Summary

A 1500 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 2554 ng/J was obtained. This is approximately 72% higher than the value of 1481 ng/J (55 400 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

2.1.10.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

2.1.10.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

2.1.10.4 Results

(1) Basic Data:

Field Work

Date: February 27, 1986
Location: Harmatten Area
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Ingersol Rand
Model - kVS (Turbo)
Rated Power Level - 1500 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 7.0°C
Barometric Pressure: 664.97 mm Hg
Relative Humidity: 34%

Lab Work

Date: March 3, 1986
Location: Calgary
Ambient Temperature: 21.0°C
Barometric Pressure: 674.5 mm Hg

(2) Gas Analysis:

Table 48. Flue gas composition: NO_x test report No. R-10.

Component	Sample 1	Mole Percent Sample 2	Average Composition
H_2	0.0000	0.0000	0.0000
Ar	0.9879	0.9854	0.9867
O_2	8.3292	9.2148	8.7720
N_2	82.5981	82.3882	82.4932
C_1	0.2030	0.1889	0.1959
CO	0.0169	0.0162	0.0165
CO_2	7.7925	7.1453	7.4689
C_2	0.0690	0.0580	0.0635
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0034	0.0032	0.0033
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
iC_4	0.0000	0.0000	0.0000
nC_4	0.0000	0.0000	0.0000
iC_5	0.0000	0.0000	0.0000
nC_5	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

Table 49. Fuel gas composition: NO_x test report No. R-10.

Component	Mole Percent
H_2	0.0000
Ar	0.0000
O_2	0.0000
N_2	0.0892
C_1	68.1466
CO	0.0000
CO_2	6.9032
C_2	23.6125
H_2S	0.0000
COS	0.0000
C_3	1.2307
SO_2	0.0000
CS_2	0.0000
i-C_4	0.0051
n-C_4	0.0036
i-C_5	0.0052
n-C_5	0.0039
C_6+	0.0000
	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.1788 m^3
Meter Pressure -	664.97 mm Hg
Meter Temperature -	24.3°C
Impinger Pressure -	614.17 mm Hg
Moles of Dried Flue Gas Metered -	6.41 g - moles
Volume of H_2O Condensed -	11 ml
Moles of H_2O Condensed -	0.61 g - moles
Vapour Pressure of Drier -	8.611 mm Hg
Moles of H_2O Vapour -	0.09 g - moles
Total Moles of Wet Flue Gas -	7.11 g - moles
H_2O Concentration -	9.85 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 50. NO_x determination - field data: NO_x test report No. R-10.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
4	12:18	30	2105.2	57.73	664.97	7
18	12:21	30	2041.2	42.49	664.97	7
32	12:24	30	2004.0	43.76	664.97	7
33	13:02	30	2008.0	34.87	670.05	7
17	13:07	30	2102.8	41.22	664.97	7
10	13:09	30	2080.7	47.57	667.51	7

(b) Lab Data:

Table 51. NO_x determination - lab data: NO_x test report No. R-10.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
4	664.34	21.0	2854.55
18	674.50	21.0	3273.47
32	659.26	21.0	3075.96
33	649.10	21.0	2868.85
17	659.26	21.0	3389.89
10	674.50	21.0	3195.92

Representative NO_x Concentration**: 3103.55 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 52. Overall gas compositions: NO_x test report No. R-10.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	9.8500
NO_x	0.0000	0.0000	0.3104
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.9867	0.8865
O_2	0.0000	8.7720	7.8807
N_2	0.0892	82.4932	74.1116
CO	0.0000	0.0165	0.0148
CO_2	6.9032	7.4689	6.7100
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
C_1	68.1466	0.1959	0.1760
C_2	23.6125	0.0635	0.0570
C_3	1.2307	0.0033	0.0030
i-C_4	0.0051	0.0000	0.0000
n-C_4	0.0036	0.0000	0.0000
i-C_5	0.0052	0.0000	0.0000
n-C_5	0.0039	0.0000	0.0000
C_6	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 17.9456

Gross heating value of fuel gas = 42.46 MJ/m^3

= 1003 MJ/kmole

(c) NO$_x$ Emission Factor

Using equation (2), the NO$_x$ emission factor is given by:

$$EF = \frac{0.3104 \cdot 17.9456 \cdot 46.0055 \cdot 10^6}{100 \cdot 1003}$$

$$= 2554 \text{ ng/J}$$

The NO$_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 72% higher than this EPA number.

2.1.10.5 Conclucions

The NO$_x$ emission factor for the tested reciprocating engine is 2554 ng/J.

2.1.11 Natural Gas Fueled Engines: NO_x Test Report No. R-11

Test Date: February 27, 1986
Test Location: Harmatten Area
Tested By: T. Seedhouse & C. Scott

2.1.11.1 Summary

A 1120 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 1341 ng/J was obtained. This is approximately 9% lower than the value of 1481 ng/J (55 400 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

2.1.11.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

2.1.11.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

2.1.11.4 Results

(1) Basic Data:

Field Work

Date: February 27, 1986
Location: Harmatten Area
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Ingersol Rand
Model - kVGB
Rated Power Level - 1120 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 12.0°C
Barometric Pressure: 664.97 mm Hg
Relative Humidity: 34%

Lab Work

Date: March 3, 1986
Location: Calgary
Ambient Temperature: 21.0°C
Barometric Pressure: 674.50 mm Hg

(2) Gas Analysis:

Table 53. Flue gas composition: NO_x test report No. R-11.

Component	Mole Percent Sample 1	Mole Percent Sample 2	Average Composition
H_2	0.0000	0.0000	0.0000
Ar	0.9826	0.9875	0.9850
O_2	6.7350	5.6206	6.1778
N_2	82.1539	82.5712	82.3626
C_1	0.7469	0.7909	0.7689
CO	0.0127	0.0191	0.0159
CO_2	9.0805	9.7036	9.3920
C_2	0.2733	0.2908	0.2821
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0151	0.0164	0.0157
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
iC_4	0.0000	0.0000	0.0000
nC_4	0.0000	0.0000	0.0000
iC_5	0.0000	0.0000	0.0000
nC_5	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

Table 54. Fuel gas composition: NO_x test report No. R-11.

Component	Mole Percent
H_2	0.0000
Ar	0.0000
O_2	0.0000
N_2	0.0892
C_1	68.1466
CO	0.0000
CO_2	6.9032
C_2	23.6125
H_2S	0.0000
COS	0.0000
C_3	1.2307
SO_2	0.0000
CS_2	0.0000
i-C_4	0.0051
n-C_4	0.0036
i-C_5	0.0052
n-C_5	0.0039
C_6+	0.0000
	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.1883 m^3
Meter Pressure -	664.97 mm Hg
Meter Temperature -	26.7°C
Impinger Pressure -	614.17 mm Hg
Moles of Dried Flue Gas Metered -	6.70 g - moles
Volume of H_2O Condensed -	15 ml
Moles of H_2O Condensed -	0.83 g - moles
Vapour Pressure of Drier -	6.5430 mm Hg
Moles of H_2O Vapour -	0.07 g - moles
Total Moles of Wet Flue Gas -	7.60 g - moles
H_2O Concentration -	11.88 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 55. NO_x determination - field data: NO_x test report No. R-11.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
2	13:36	30	2105.2	43.94	664.97	12
5	13:39	30	2041.5	35.05	664.97	12
20	13:42	30	2079.9	35.05	664.97	12
35	14:20	30	2002.0	52.83	664.97	12
15	14:23	30	2027.3	68.07	664.97	12
Broken	-	-	-	-	-	-

(b) Lab Data:

Table 56. NO_x determination - lab data: NO_x test report No. R-11.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
2	649.10	21.0	3016.95
5	654.18	21.0	2797.97
20	608.46	21.0	2716.05
35	661.80	21.0	3493.27
15	664.34	21.0	2989.28
-	-	-	-

Representative NO_x Concentration**: 2201.05 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 57. Overall gas compositions: NO_x test report No. R-11.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	11.8800
NO_x	0.0000	0.0000	0.2201
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.9850	0.8658
O_2	0.0000	6.1778	5.4303
N_2	0.0892	82.3626	72.3966
CO	0.0000	0.0159	0.0140
CO_2	6.9032	9.3920	8.2556
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
C_1	68.1466	0.7689	0.6759
C_2	23.6125	0.2821	0.2480
C_3	1.2307	0.0157	0.0138
i-C_4	0.0051	0.0000	0.0000
n-C_4	0.0036	0.0000	0.0000
i-C_5	0.0052	0.0000	0.0000
n-C_5	0.0039	0.0000	0.0000
C_6	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 13.2923

Gross heating value of fuel gas = 42.46 MJ/m^3
= 1003 MJ/kmole

(c) NO$_x$ Emission Factor

Using equation (2), the NO$_x$ emission factor is given by:

$$EF = \frac{0.2201 \cdot 13.2923 \cdot 46.0055 \cdot 10^6}{100 \cdot 1003}$$

$$= 1341 \text{ ng/J}$$

The NO$_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 9% lower than this EPA number.

2.1.11.5 Conclusions

The NO$_x$ emission factor for the tested reciprocating engine is 1341 ng/J.

2.1.12 Natural Gas Fueled Engines: NO_x Test Report No. R-12

Test Date: February 27, 1986
Test Location: Harmatten Area
Tested By: T. Seedhouse & C. Scott

2.1.12.1 Summary

A 1120 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 504 ng/J was obtained. This is approximately 66% lower than the value of 1481 ng/J (55 400 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

2.1.12.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

2.1.12.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

2.1.12.4 Results

(1) Basic Data:

Field Work

Date: February 27, 1986
Location: Harmatten Area
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Ingersol Rand
Model - kVGR
Rated Power Level - 1120 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 7.0°C
Barometric Pressure: 664.97 mm Hg
Relative Humidity: 34%

Lab Work

Date: March 3, 1986
Location: Calgary
Ambient Temperature: 21.0°C
Barometric Pressure: 674.50 mm Hg

(2) Gas Analysis:

Table 58. Flue gas composition: NO_x test report No. R-12.

Component	Mole Percent Sample 1	Sample 2	Average Composition
H_2	0.8683	1.3162	1.0922
Ar	0.9857	1.0012	0.9934
O_2	5.9938	1.9344	3.9641
N_2	82.4134	83.7129	83.0632
C_1	0.0353	0.0090	0.0222
CO	1.7241	2.1823	1.9532
CO_2	7.9776	9.8440	8.9108
C_2	0.0018	0.0000	0.0009
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
iC_4	0.0000	0.0000	0.0000
nC_4	0.0000	0.0000	0.0000
iC_5	0.0000	0.0000	0.0000
nC_5	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

Table 59. Fuel gas composition: NO_X test report No. R-12.

Component	Mole Percent
H_2	0.0000
Ar	0.0000
O_2	0.0000
N_2	1.1044
C_1	85.9195
CO	0.0000
CO_2	0.0184
C_2	11.9428
H_2S	0.0000
COS	0.0000
C_3	0.9762
SO_2	0.0000
CS_2	0.0000
i-C_4	0.0152
n-C_4	0.0079
i-C_5	0.0087
n-C_5	0.0069
C_6+	0.0000
	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.1713 m^3
Meter Pressure -	664.97 mm Hg
Meter Temperature -	29.4°C
Impinger Pressure -	614.17 mm Hg
Moles of Dried Flue Gas Metered -	6.04 g - moles
Volume of H_2O Condensed -	20 ml
Moles of H_2O Condensed -	1.11 g - moles
Vapour Pressure of Drier -	8.611 mm Hg
Moles of H_2O Vapour -	0.09 g - moles
Total Moles of Wet Flue Gas -	7.23 g - moles
H_2O Concentration -	16.51 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 60. NO_x determination - field data: NO_x test report No. R-12.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
6	14:37	30	2033.4	60.45	664.97	7
34	14:40	30	2003.0	57.91	664.97	7
11	14:42	30	2086.6	57.91	664.97	7
8	15:18	30	2067.5	57.91	664.97	7
3	15:20	30	2054.3	68.07	664.97	7
9	15:22	30	2038.4	68.07	664.97	7

(b) Lab Data:

Table 61. NO_x determination - lab data: NO_x test report No. R-12.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
6	679.58	21.0	849.54
34	677.04	21.0	857.33
11	674.50	21.0	820.97
8	656.72	21.0	884.10
3	674.50	21.0	846.27
9	674.50	21.0	901.73

Representative NO_x Concentration**: 859.31 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 62. Overall gas compositions: NO_x test report No. R-12.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	16.5100
NO_x	0.0000	0.0000	0.0859
H_2	0.0000	1.0922	0.9109
Ar	0.0000	0.9934	0.8285
O_2	0.0000	3.9641	3.3062
N_2	1.1044	83.0632	69.2781
CO	0.0000	1.9532	1.6290
CO_2	0.0184	8.9108	7.4320
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
C_1	85.9195	0.0222	0.0185
C_2	11.9428	0.0009	0.0008
C_3	0.9762	0.0000	0.0000
i-C_4	0.0152	0.0000	0.0000
n-C_4	0.0079	0.0000	0.0000
i-C_5	0.0087	0.0000	0.0000
n-C_5	0.0069	0.0000	0.0000
C_6	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 12.4350

Gross heating value of fuel gas = 41.24 MJ/m^3
= 975 MJ/kmole

(c) NO_x Emission Factor

Using equation (2), the NO_x emission factor is given by:

$$EF = \frac{0.0859 \cdot 12.4350 \cdot 46.0055 \cdot 10^6}{100 \cdot 975}$$

$$= 504 \text{ ng/J}$$

The NO_x emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 66% lower than this EPA number.

2.1.12.5 Conclusions

The NO_x emission factor for the tested reciprocating engine is 504 ng/J.

2.2 INDIVIDUAL REPORTS FOR THE SURVEYED TURBINE ENGINES

The individual reports prepared for each of the six turbine engines surveyed are presented in the following. Since the Introduction and Procedure sections of each report are basically the same, these have been omitted from all but the first report to avoid repetition.

2.2.1 ′ Natural Gas Fueled Engines: NO_x Test Report No. T-1

Test Date: November 14, 1985
Test Location: Cochrane Area
Tested By: R. Tamura & D. Picard

2.2.1.1 Summary

A 18 540 kW natural gas fueled turbine engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 124.2 ng/J was obtained. This agrees well with the value of 126 ng/J (4700 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled turbine engines.

2.2.1.2 Introduction

In Alberta, the primary industrial source of NO_x emissions is the internal combustion engine (i.e., large turbine and reciprocating engines). The amount of NO_x emitted from these units is normally estimated using emission factors. Emission factors express NO_x emissions in terms of nanograms per joule of fuel consumed (ng/J).

Production of NO_x is a complex process. Ambient temperature, pressure and humidity, and operating conditions are all known to have a significant effect. Subsequently, the use of emission factors provides only a rough approximation of actual emissions. In order to obtain NO_x emission factors that will best approximate NO_x emissions in Alberta, a number of representative emission sources are being tested (Alberta-specific emission factors are not currently available).

In Alberta, the vast majority of industrial turbine and reciprocating engines are natural gas fueled. Therefore only natural gas fueled engines are being considered.

A minimum of six turbine engines and six reciprocating engines of various power levels will be tested. In this report NO_x testing of a 18 540 kW turbine engine is discussed.

2.2.1.3 Procedure

(1) The following basic data were recorded:

- location,
- date,
- ambient temperature,
- relative humidity,
- barometric pressure,
- test crew, and
- test unit description.

(2) Duplicate samples of both the fuel and flue gases were collected and subsequently analyzed by a gas chromatograph. These analyses were used to obtain a single representative NO_x and H_2O free composition of both the fuel and flue gases.

(3) The moisture content of the flue gas was determined using a half hour condensation test as described under Method 3 in the Alberta Environment Stack Sampling Code (1976).

Any natural gas mixture supplied as fuel to an internal combustion engine will contain much less than 1% H_2O. Moisture levels of this magnitude are insignificant in terms of calculating NO_x emission factors. Therefore, moisture content of the fuel gas was not determined.

(4) The NO_x content of the flue gas was determined using the NO_x testing procedure described under Method 6 in the Alberta Environment Stack Sampling Code (1976). Two triplicate tests were performed (i.e., 6 NO_x samples were taken). Results of these tests were used to obtain a single representative NO_x concentration for the flue gas.

(5) Using the results of (2), (3) and (4) an overall representative composition was determined for the flue gas. The overall reaction for the combustion process is expressed as:

$$\begin{bmatrix}\text{Overall}\\ \text{Fuel Gas}\\ \text{Composition}\end{bmatrix} + a \begin{bmatrix}\text{Overall}\\ \text{Composition}\\ \text{of the Air}\end{bmatrix} \rightarrow b \begin{bmatrix}\text{Overall}\\ \text{Flue Gas}\\ \text{Composition}\end{bmatrix} \qquad (1)$$

where "a" and "b" are stoichiometric coefficients. If it is assumed that the concentration of carbon compounds is negligible in the air then the coefficient "b" may be obtained by balancing the carbon atoms between the fuel gas and the flue gas compositions.

An analysis of the air was not conducted nor was "a" evaluated, as this information was not required.

The NO_x emission factor was calculated using the following equation:

$$EF = \frac{y\,(NO_x) \cdot b \cdot M\,(NO_2) \cdot g_c}{\begin{array}{c}\text{100 kmoles of}\\ \text{fuel gas}\end{array} \cdot \Delta H} \qquad (2)$$

where,

EF = NO_x emission factor, ng of NO_x/J of fuel gas
y (NO_x) = mole percent of NO_x expressed as an NO_2 equivalent
M (NO_2) = molecular weight of NO_2
= 46.0055 kg/kmole
g_c = conversion factor
= 10^6
ΔH = gross heat value of the fuel gas, MJ/kmole

2.2.1.4 Results

(1) Basic Data:

Field Work

Date: November 14, 1985
Location: Cochrane Area
Test Crew: R. Tamura & D. Picard

Test Unit: Make - General Electric
Model - 5332 B
Rated Power Level - 18 540 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 3°C
Barometric Pressure: 653.03 mm Hg
Relative Humidity: 26%

Lab Work

Date: December 4, 1985
Location: Calgary
Ambient Temperature: 22°C
Barometric Pressure: 669.60 mm Hg

(2) Gas Analysis:

Table 63. Flue gas composition: NO_x test report No. T-1.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.9586	0.9590	0.9588
O_2	16.0669	16.0030	16.0350
N_2	80.1543	80.1804	80.1673
C_1	0.0000	0.0000	0.0000
CO	0.0022	0.0026	0.0024
CO_2	2.8180	2.8550	2.8365
C_2	0.0000	0.0000	0.0000
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

Table 64. Fuel gas composition: NO_x test report No. T-1.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000
N_2	1.2214	1.1940	1.2077
C_1	97.2356	97.2630	97.2493
CO	0.0000	0.0000	0.0000
CO_2	0.3111	0.3097	0.3104
C_2	1.2143	1.2158	1.2151
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0176	0.0175	0.0175
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
$i\text{-}C_4$	0.0000	0.0000	0.0000
$n\text{-}C_4$	0.0000	0.0000	0.0000
$i\text{-}C_5$	0.0000	0.0000	0.0000
$n\text{-}C_5$	0.0000	0.0000	0.0000
C_6	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.1696 m^3
Meter Pressure -	653.03 mm Hg
Meter Temperature -	11.6°C
Impinger Pressure -	627.63 mm Hg
Moles of Dried Flue Gas Metered -	6.24 g - moles
Volume of H_2O Condensed -	5 ml
Moles of H_2O Condensed -	0.28 g - moles
Vapour Pressure of Drier -	6.543 mm Hg
Moles of H_2O Vapour -	0.07 g - moles
Total Moles of Wet Flue Gas -	6.58 g - moles
H_2O Concentration -	5.21 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 65. NO_x determination - field data: NO_x test report No. T-1.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
27	10:22	30	2020.0	56.13	653.03	3
26	10:24	30	2020.0	56.13	650.49	3
28	10:26	30	2001.0	56.13	650.49	3
23	11:42	30	1992.7	56.13	650.49	3
22	11:45	30	2024.7	56.13	650.49	3
9A	11:47	30	2038.4	56.13	653.03	3

(b) Lab Data:

Table 66. NO_x determination - lab data: NO_x test report No. T-1.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
27	667.06	22	52.94
26	669.60	22	64.28
28	679.76	22	67.66
23	684.84	22	67.94
22	669.60	22	164.28
9A	689.92	22	57.41

Representative NO_x Concentration*: 64.32 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas both the high and low values were discarded and an average was taken of the remaining 4 readings. Condensation in the sample tubes may have been the cause for the abnormally large NO_x concentration for flask 22.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 67. Overall gas compositions: NO_x test report No. T-1.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	5.2100
NO_x	0.0000	0.0000	0.0064
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.9588	0.9088
O_2	0.0000	16.0350	15.1985
N_2	1.2077	80.1673	75.9854
CO	0.0000	0.0024	0.0023
CO_2	0.3104	2.8365	2.6885
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
C_1	97.2493	0.0000	0.0000
C_2	1.2151	0.0000	0.0000
C_3	0.0175	0.0000	0.0000
i-C_4	0.0000	0.0000	0.0000
n-C_4	0.0000	0.0000	0.0000
i-C_5	0.0000	0.0000	0.0000
n-C_5	0.0000	0.0000	0.0000
C_6	0.0000	0.0000	0.0000
C_7+	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 37.1793

Gross heating value of fuel gas = 37.48 MJ/m^3

= 885 MJ/kmole

(c) NO_x Emission Factor

Using equation (2), the NO_x emission factor is given by:

$$EF = \frac{0.006432 \cdot 37.1793 \cdot 46.0055 \cdot 10^6}{100 \cdot 885}$$

$$= 124.2 \text{ ng/J}$$

The NO_x emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled turbine engines is 126 ng/J. The value obtained here is approximately 1.4% less than this EPA number.

2.2.1.5 Conclusions

The NO_x emission factor for the tested turbine engine is 124.2.

2.2.2 Natural Gas Fueled Engines: NO_x Test Report No. T-2

Test Date: December 10, 1985
Test Location: Clearwater Area
Tested By: R. Tamura & M. Towill

2.2.2.1 Summary

A 17 310 kW natural gas fueled turbine engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 122.9 ng/J was obtained. This is approximately 2% lower than the value of 126 ng/J (4700 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

2.2.2.2 Introduction

See Report T-1 (i.e., Section 2.2.1.2).

2.2.2.3 Procedure

See Report T-1 (i.e., Section 2.2.1.3).

2.2.2.4 Results

(1) Basic Data:

Field Work

Date: December 10, 1985
Location: Clearwater Area
Test Crew: R. Tamura & M. LaCoste

Test Unit: Make - General Electric
Model - 7LM
Rated Power Level - 17 310 kW
Service - Driver for a natural gas compressor

Ambient Temperature: -10°C
Barometric Pressure: 680.72 mm Hg
Relative Humidity: 62%

Lab Work

Date: December 16, 1985
Location: Calgary
Ambient Temperature: 23°C
Barometric Pressure: 703.33 mm Hg

(2) Gas Analysis:

Table 68. Flue gas composition: NO_x test report No. T-2.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.9420	0.9422	0.9421
O_2	19.8577	19.8410	19.8493
N_2	78.7584	78.7759	78.7672
C_1	0.0000	0.0000	0.0000
CO	0.0021	0.0014	0.0018
CO_2	0.4398	0.4395	0.4396
C_2	0.0000	0.0000	0.0000
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

Table 69. Fuel gas composition: NO_x test report No. T-2.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000
N_2	0.6735	0.6851	0.6793
C_1	91.9135	91.8443	91.8796
CO	0.0000	0.0000	0.0000
CO_2	0.5749	0.5880	0.5814
C_2	5.4171	5.4356	5.4263
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	1.0494	1.0486	1.0490
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
$i\text{-}C_4$	0.1284	0.1298	0.1291
$n\text{-}C_4$	0.1935	0.1963	0.1949
$i\text{-}C_5$	0.0152	0.0357	0.0254
$n\text{-}C_5$	0.0291	0.0301	0.0296
C_6	0.0054	0.0065	0.0060
	100.0000	100.0000	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.1435 m^3
Meter Pressure -	680.70 mm Hg
Meter Temperature -	10°C
Impinger Pressure -	607.67 mm Hg
Moles of Dried Flue Gas Metered -	5.53 g - moles
Volume of H_2O Condensed -	4 ml
Moles of H_2O Condensed -	0.22 g - moles
Vapour Pressure of Drier -	4.582 mm Hg
Moles of H_2O Vapour -	0.04 g - moles
Total Moles of Wet Flue Gas -	5.80 g - moles
H_2O Concentration -	4.55 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 70. NO_x determination - field data: NO_x test report No. T-2.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
11	12:00	30	2086.60	53.32	617.20	-10
3	12:02	30	2054.30	48.22	551.16	-10
18	12:04	30	2041.20	53.32	617.20	-10
9	13:14	30	2038.40	66.02	551.16	-10
5	13:16	30	2041.50	66.02	551.16	-10
20	13:18	30	2079.90	66.02	680.70	-10

(b) Lab Data:

Table 71. NO_x determination - lab data: NO_x test report No. T-2.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
11	645.16	23	92.09
3	452.12	23	83.60
18	581.66	23	4.33
9	774.70	23	9.86
5	515.62	23	10.83
20	708.66	23	8.62

Representative NO_x Concentration*: 9.77 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas both the high and low values were discarded (i.e., flasks 11 and 18) and so was flask 3 since it was noteably larger than the remaining values. Condensation in the sample tubes may have been the cause for the two abnormally large NO_x concentrations.

(5) Detérmination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 72. Overall gas compositions: NO_x test report No. T-2.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	4.5500
NO_x	0.0000	0.0000	0.0010
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.9421	0.8992
O_2	0.0000	19.8493	18.9460
N_2	0.6793	78.7672	75.1825
CO	0.0000	0.0018	0.0017
CO_2	0.5814	0.4396	0.4196
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
C_1	91.8790	0.0000	0.0000
C_2	5.4263	0.0000	0.0000
C_3	1.0490	0.0000	0.0000
$i-C_4$	0.1291	0.0000	0.0000
$n-C_4$	0.1949	0.0000	0.0000
$i-C_5$	0.0254	0.0000	0.0000
$n-C_5$	0.0296	0.0000	0.0000
C_6	0.0060	0.0000	0.0000
	100.0000	100.0000	100.0000

b) Other Information:

Stoichiometric Coefficient "b" = 256.50

Gross heating value of fuel gas = $39.69\ MJ/m^3$
= 938 MJ/kmole

(c) NO_x Emission Factor

Using equation (2), the NO_x emission factor is given by:

$$EF = \frac{0.000977 \cdot 256.50 \cdot 46.0055 \cdot 10^6}{100 \cdot 938}$$

$$= 122.9\ ng/J$$

The NO_x emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled turbine engines is 126 ng/J. The value obtained here is approximately 2.46% less than this EPA number.

2.2.2.5 Conclusions

The NO_x emission factor for the tested turbine engine is 122.9 ng/J.

2.2.3 Natural Gas Fueled Engines: NO_x Test Report No. T-3

Test Date: January 6, 1986
Test Location: Burton Creek Area
Tested By: T. Seedhouse & B. Reshetylo

2.2.3.1 Summary

A 9 025 kW natural gas fueled turbine engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 46.8 ng/J was obtained. This is approximately 63% lower than the value of 126 ng/J (4700 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

2.2.3.2 Introduction

See Report T-1 (i.e., Section 2.2.1.2).

2.2.3.3 Procedure

See Report T-1 (i.e, Section 2.2.1.3).

2.2.3.4 Results

(1) Basic Data:

Field Work

Date: January 6, 1986
Location: Burton Creek Area
Test Crew: T. Seedhouse & B. Reshetylo

Test Unit: Make - Cooper - Bessemer
Model - RT48
Rated Power Level - 9 025 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 7°C
Barometric Pressure: 687.07 mm Hg
Relative Humidity: 50%

Lab Work

Date: January 8, 1986
Location: Calgary
Ambient Temperature: 22°C
Barometric Pressure: 665.23 mm Hg

(2) Gas Analysis:

Table 73. Flue gas composition: NO_X test report No. T-3.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.9360	0.9354	0.9357
O_2	19.5505	19.5600	19.5553
N_2	78.2590	78.2098	78.2344
C_1	0.0666	0.0773	0.0719
CO	0.0245	0.0243	0.0244
CO_2	1.1634	1.1932	1.1783
C_2	0.0000	0.0000	0.0000
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

Table 74. Fuel gas composition: NO_x test report No. T-3.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000
N_2	1.0914	1.1061	1.0987
C_1	97.4524	97.4396	97.4460
CO	0.0000	0.0000	0.0000
CO_2	0.2674	0.2628	0.2651
C_2	1.1439	1.1444	1.1441
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0389	0.0392	0.0390
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
$i\text{-}C_4$	0.0018	0.0021	0.0020
$n\text{-}C_4$	0.0034	0.0037	0.0036
$i\text{-}C_5$	0.0004	0.0011	0.0008
$n\text{-}C_5$	0.0005	0.0010	0.0007
C_6	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.1557 m^3
Meter Pressure -	687.07 mm Hg
Meter Temperature -	20.7°C
Impinger Pressure -	636.27 mm Hg
Moles of Dried Flue Gas Metered -	5.84 g - moles
Volume of H_2O Condensed -	4 ml
Moles of H_2O Condensed -	0.22 g - moles
Vapour Pressure of Drier -	8.494 mm Hg
Moles of H_2O Vapour -	0.08 g - moles
Total Moles of Wet Flue Gas -	6.14 g - moles
H_2O Concentration -	4.90 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 75. NO_x determination - field data: NO_x test report No. T-3.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
28	12:12	30	2001.0	97.79	687.07	5
9A	12:15	30	2038.4	97.79	687.07	5
23	12:18	30	1992.7	97.79	687.07	5
26	13:04	30	2020.0	97.79	687.07	5
22	13:07	30	2024.7	85.09	687.07	5
27	13:10	30	2020.0	95.25	687.07	5

(b) Lab Data:

Table 76. NO_x determination - lab data: NO_x test report No. T-3.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
28	660.15	22	10.71
9A	665.23	22	11.15
23	657.61	22	11.31
26	652.53	22	9.01
22	642.37	22	10.92
27	644.91	22	10.85

Representative NO_x Concentration*: 10.91 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 77. Overall gas compositions: NO_x test report No. T-3.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	4.9000
NO_x	0.0000	0.0000	0.0011
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.9357	0.8898
O_2	0.0000	19.5553	18.5969
N_2	1.0987	78.2344	74.4000
CO	0.0000	0.0244	0.0232
CO_2	0.2651	1.1783	1.1206
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
C_1	97.4460	0.0719	0.0684
C_2	1.1441	0.0000	0.0000
C_3	0.0390	0.0000	0.0000
$i-C_4$	0.0020	0.0000	0.0000
$n-C_4$	0.0036	0.0000	0.0000
$i-C_5$	0.0008	0.0000	0.0000
$n-C_5$	0.0007	0.0000	0.0000
C_6	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 82.6200

Gross heating value of fuel gas = 37.53 MJ/m^3
= 887 MJ/kmole

(c) NO_x Emission Factor

Using equation (2), the NO_x emission factor is given by:

$$EF = \frac{0.001091 \cdot 82.6200 \cdot 46.0055 \cdot 10^6}{100 \cdot 887}$$

$$= 46.8 \text{ ng/J}$$

The NO_x emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled turbine engines is 126 ng/J. The value obtained here is approximately 63% less than this EPA number.

2.2.3.5 Conclusions

The NO_x emission factor for the tested turbine engine is 46.8 ng/J.

2.2.4 Natural Gas Fueled Engines: NO_x Test Report No. T-4

Test Date: January 8, 1986
Test Location: Princess Area
Tested By: R. Tamura & M. Towill

2.2.4.1 Summary

A 25 975 kW natural gas fueled turbine engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 72.9 ng/J was obtained. This is approximately 42% lower than the value of 126 ng/J (4700 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled turbine engines.

2.2.4.2 Introduction

See Report T-1 (i.e., Section 2.2.1.2).

2.2.4.3 Procedure

See Report T-1 (i.e., Section 2.2.1.3).

2.2.4.4 Results

(1) Basic Data:

Field Work

Date: January 8, 1986
Location: Princess Area
Test Crew: R. Tamura & M. Towill

Test Unit: Make - Pratt & Whittney
Model - FT-4C
Rated Power Level - 25 975 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 20°C
Barometric Pressure: 664.46 mm Hg
Relative Humidity: 36%

Lab Work

Date: January 13, 1986
Location: Calgary
Ambient Temperature: 20.0°C
Barometric Pressure: 671.83 mm Hg

(2) Gas Analysis:

Table 78. Flue gas composition: NO_x test report No. T-4.

Component	Sample 1	Mole Percent Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.9543	0.9528	0.9536
O_2	16.8659	16.9388	16.9024
N_2	79.7921	79.6646	79.7283
C_1	0.0000	0.0000	0.0000
CO	0.0091	0.0095	0.0093
CO_2	2.3714	2.4182	2.3948
C_2	0.0000	0.0000	0.0000
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0000	0.0000	0.0000
SO_2	0.0072	0.0161	0.0116
	100.0000	100.0000	100.0000

Table 79. Fuel gas composition: NO_x test report No. T-4.

Component	Mole Percent
H_2	0.0000
Ar	0.0000
O_2	0.0000
N_2	2.9818
C_1	88.0874
CO	0.0000
CO_2	1.1438
C_2	6.0703
H_2S	0.0000
COS	0.0000
C_3	1.4882
SO_2	0.0000
CS_2	0.0000
i-C_4	0.0405
n-C_4	0.0583
i-C_5	0.0280
n-C_5	0.0226
C_6	0.0791
C_7+	0.0000
	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.1849 m^3
Meter Pressure -	664.46 mm Hg
Meter Temperature -	20.8°C
Impinger Pressure -	591.44 mm Hg
Moles of Dried Flue Gas Metered -	6.70 g - moles
Volume of H_2O Condensed -	6 ml
Moles of H_2O Condensed -	0.33 g - moles
Vapour Pressure of Drier -	9.2100 mm Hg
Moles of H_2O Vapour -	0.11 g - moles
Total Moles of Wet Flue Gas -	7.14 g - moles
H_2O Concentration -	6.14 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 80. NO_x determination - field data: NO_x test report No. T-4.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
18	13:15	30	2041.2	30.84	656.84	25
9	13:18	30	2038.4	25.76	654.30	25
2	13:20	30	2105.2	25.76	651.76	25
15	14:11	30	2027.3	23.22	656.84	25
5	14:13	30	2041.5	23.22	656.84	25
20	14:15	30	2079.9	20.68	641.60	25

(b) Lab Data:

Table 81. NO_x determination - lab data: NO_x test report No. T-4.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
18	697.23	20	33.96
9	699.77	20	31.88
2	695.96	20	33.49
15	691.64	20	6.11
5	702.31	20	28.13
20	720.09	20	29.58

Representative NO_x Concentration*: 30.77 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 82. Overall gas compositions: NO_x test report No. T-4.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	6.1400
NO_x	0.0000	0.0000	0.0031
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.9536	0.8950
O_2	0.0000	16.9024	15.8641
N_2	2.9818	79.7283	74.8305
CO	0.0000	0.0093	0.0087
CO_2	1.1438	2.3948	2.2477
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0116	0.0109
CS_2	0.0000	0.0000	0.0000
C_1	88.0874	0.0000	0.0000
C_2	6.0703	0.0000	0.0000
C_3	1.4882	0.0000	0.0000
i-C_4	0.0405	0.0000	0.0000
n-C_4	0.0583	0.0000	0.0000
i-C_5	0.0280	0.0000	0.0000
n-C_5	0.0226	0.0000	0.0000
C_6	0.0791	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 47.4023

Gross heating value of fuel gas = 38.95 MJ/m^3
= 920 MJ/kmole

(c) NO$_x$ Emission Factor

Using equation (2), the NO$_x$ emission factor is given by:

$$EF = \frac{0.003077 \cdot 47.4023 \cdot 46.0055 \cdot 10^6}{100 \cdot 920}$$

$$= 72.9 \text{ ng/J}$$

The NO$_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled turbine engines is 126 ng/J. The value obtained here is approximately 42% less than this EPA number.

2.2.4.5 Conclusions

The NO$_x$ emission factor for the tested turbine engine is 72.9 ng/J.

2.2.5 Natural Gas Fueled Engines: NO_x Test Report No. T-5

Test Date: January 8, 1986
Test Location: Hussar Area
Tested By: B. Reshetylo & T. Seedhouse

2.2.5.1 Summary

A 8690 kW natural gas fueled turbine engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 97.9 ng/J was obtained. This is approximately 22% lower than the value of 126 ng/J (4700 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled turbine engines.

2.2.5.2 Introduction

See Report T-1 (i.e., Section 2.2.1.2).

2.2.5.3 Procedure

See Report T-1 (i.e., Section 2.2.1.3).

2.2.5.4 Results

(1) Basic Data:

Field Work

Date: January 8, 1986
Location: Hussar Area
Test Crew: T. Seedhouse & B. Reshetylo

Test Unit: Make - Ingersol Rand
Model - JP-125
Rated Power Level - 8 690 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 3°C
Barometric Pressure: 664.46 mm Hg
Relative Humidity: 36%

Lab Work

Date: January 13, 1986
Location: Calgary
Ambient Temperature: 20.0°C
Barometric Pressure: 671.83 mm Hg

(2) Gas Analysis:

Table 83. Flue gas composition: NO_x test report No. T-5.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.9531	0.9545	0.9538
O_2	17.2680	17.1713	17.2196
N_2	79.6921	79.8046	79.7484
C_1	0.0000	0.0000	0.0000
CO	0.0089	0.0084	0.0086
CO_2	2.0779	2.0612	2.0696
C_2	0.0000	0.0000	0.0000
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

Table 84. Fuel gas composition: NO_x test report No. T-5.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000
N_2	0.7704	0.9624	0.8664
C_1	92.3799	92.2341	92.3070
CO	0.0000	0.0000	0.0000
CO_2	0.5628	0.5616	0.5622
C_2	4.8903	4.8604	4.8754
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.9682	0.9619	0.9650
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
i-C_4	0.1319	0.1321	0.1320
n-C_4	0.2006	0.2020	0.2013
i-C_5	0.0448	0.0462	0.0455
n-C_5	0.0367	0.0353	0.0360
C_6	0.0144	0.0040	0.0092
	100.0000	100.0000	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered -	0.1699 m^3
Meter Pressure -	664.46 mm Hg
Meter Temperature -	11.9°C
Impinger Pressure -	613.66 mm Hg
Moles of Dried Flue Gas Metered -	6.35 g - moles
Volume of H_2O Condensed -	4 ml
Moles of H_2O Condensed -	0.22 g - moles
Vapour Pressure of Drier -	8.047 mm Hg
Moles of H_2O Vapour -	0.08 g - moles
Total Moles of Wet Flue Gas -	6.66 g - moles
H_2O Concentration -	4.60 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 85. NO_x determination - field data: NO_x test report No. T-5.

Flask Number	Time	Volume (ml) Absorbing Solution	Volume (ml) Flask	Flask Pressure (mm Hg) Evacuated	Flask Pressure (mm Hg) Filled	Flask Temperature (°C)
9A	11:37	30	2038.40	49.78	664.46	0
23	11:41	30	1992.70	39.62	664.46	0
26	11:45	30	2020.00	37.08	667.00	0
22	12:25	30	2024.70	39.62	667.00	0
28	12:29	30	2001.00	44.70	664.46	0
27	12:33	30	2020.00	39.62	667.00	0

(b) Lab Data:

Table 86. NO_x determination - lab data: NO_x test report No. T-5.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
9A	Broken	20.0	-
23	684.53	20.0	41.03
26	674.37	20.0	32.11
22	672.08	20.0	36.84
28	697.23	20.0	43.81
27	671.83	20.0	30.64

Representative NO_x Concentration*: 36.66 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas both the high and low values were discarded and an average was taken of the remaining 3 readings.

(5) Detérmination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 87. Overall gas compositions: NO_x test report No. T-5.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	0.0000
NO_x	0.0000	0.0000	0.0000
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.9538	0.9099
O_2	0.0000	17.2196	16.4269
N_2	0.8664	79.7484	76.0770
CO	0.0000	0.0086	0.0082
CO_2	0.5622	2.0696	1.9743
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
C_1	92.3070	0.0000	0.0000
C_2	4.8754	0.0000	0.0000
C_3	0.9650	0.0000	0.0000
i-C_4	0.1320	0.0000	0.0000
n-C_4	0.2013	0.0000	0.0000
i-C_5	0.0455	0.0000	0.0000
n-C_5	0.0360	0.0000	0.0000
C_6	0.0092	0.0000	0.0000
C_7+	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 54.1284

Gross heating value of fuel gas = 39.4639 MJ/m^3
= 932 MJ/kmole

(c) NO_x Emission Factor

Using equation (2), the NO_x emission factor is given by:

$$EF = \frac{0.003666 \cdot 54.1284 \cdot 46.0055 \cdot 10^6}{100 \cdot 932}$$

$$= 97.9 \text{ ng/J}$$

The NO_x emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled turbine engines is 126 ng/J. The value obtained here is approximately 22% less than this EPA number.

2.2.5.5 Conclusions

The NO_x emission factor for the tested turbine engine is 97.9 ng/J.

2.2.6 Natural Gas Fueled Engines: NO_x Test Report No. T-6

Test Date: January 13, 1986
Test Location: Harmatten Area
Tested By: T. Seedhouse & C. Scott

2.2.6.1 Summary

A 2 650 kW natural gas fueled turbine engine was tested to determine its effective oxides of nitrogen (NO_x) emission factor under field conditions (i.e., equivalent ng of NO_2 emitted per J of fuel consumed). A value of 175.7 ng/J was obtained. This is approximately 39% higher than the value of 126 ng/J (4700 kg/10^6 $\underline{N}m^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

2.2.6.2 Introduction

See Report T-1 (i.e., Section 2.2.1.2).

2.2.6.3 Procedure

See Report T-1 (i.e., Section 2.2.1.3).

2.2.6.4 Results

(1) Basic Data:

Field Work
Date: January 13, 1986
Location: Harmatten Area
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Solar - Centaur
Model - 1970
Rated Power Level - 2 650 kW
Service - Driver for a water injection pump

Ambient Temperature: 12°C
Barometric Pressure: 671.83 mm Hg
Relative Humidity: 26%

Lab Work

Date: January 14, 1986
Location: Calgary
Ambient Temperature: 21.5°C
Barometric Pressure: 668.20 mm Hg

(2) Gas Analysis:

Table 88. Flue gas composition: NO_x test report No. T-6.

Component	Mole Percent Sample 1	Sample 2	Average
H_2	0.1425	0.1446	0.1435
Ar	0.9485	0.9506	0.9496
O_2	17.3612	17.1638	17.2625
N_2	79.3064	79.4805	79.3935
C_1	0.0000	0.0000	0.0000
CO	0.0035	0.0031	0.0033
CO_2	2.2379	2.2573	2.2476
C_2	0.0000	0.0000	0.0000
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	0.0000	0.0000	0.0000
	100.0000	100.0000	100.0000

Table 89. Fuel gas composition: NO_x test report No. T-6.

Component	Sample 1	Mole Percent Sample 2	Average
H_2	0.0000	0.0000	0.0000
Ar	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000
N_2	0.6205	0.6176	0.6190
C_1	73.3170	73.1878	73.2524
CO	0.0000	0.0000	0.0000
CO_2	5.1923	5.2936	5.2430
C_2	11.9224	12.0193	11.9708
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
C_3	5.2839	5.3557	5.3198
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
i-C_4	0.8764	0.8791	0.8778
n-C_4	1.7206	1.6847	1.7027
i-C_5	0.3648	0.3493	0.3570
n-C_5	0.3958	0.3647	0.3802
C_6	0.2694	0.2198	0.2446
C_7+	0.0369	0.0284	0.0327
	100.0000	100.0000	100.0000

(3) Flue Gas Moisture Content

Volume of Flue Gas Metered - 0.1727 m^3
Meter Pressure - 671.83 mm Hg
Meter Temperature - 13.9°C
Impinger Pressure - 608.33 mm Hg
Moles of Dried Flue Gas Metered - 6.48 g - moles
Volume of H_2O Condensed - 1 ml
Moles of H_2O Condensed - 0.06 g - moles
Vapour Pressure of Drier - 8.905 mm Hg
Moles of H_2O Vapour - 0.10 g - moles
Total Moles of Wet Flue Gas - 6.63 g - moles
H_2O Concentration - 2.29 mole percent

(4) Flue Gas NO_x Content

(a) Field Data

Table 90. NO_x determination - field data: NO_x test report No. T-6.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
2	12:40	30	2105.2	57.15	671.83	10
18	12:43	30	2041.2	49.53	671.83	10
9	12:46	30	2038.4	54.61	671.83	10
15	13:35	30	2027.3	50.80	671.83	10
20	13:38	30	2079.9	44.45	671.83	10
5	13:41	30	2041.5	45.72	669.29	10

(b) Lab Data:

Table 91. NO_x determination - lab data: NO_x test report No. T-6.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x Concentration* (ppm)
2	673.28	21.5	61.91
18	670.74	21.5	75.30
9	673.28	21.5	69.48
15	670.74	21.5	61.12
20	673.28	21.5	74.06
5	670.74	21.5	62.46

Representative NO_x Concentration**: 66.98 ppm

* On a wet basis.

** To obtain a single representative NO_x concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of NO_x Emission Factor

(a) Overall Gas Compositions

Table 92. Overall gas compositions: NO_x test report No. T-6.

Component	Composition (mole percent)		
	Fuel Gas	H_2O & NO_x Free Flue Gas	Flue Gas
H_2O	0.0000	0.0000	2.2900
NO_x	0.0000	0.0000	0.0067
H_2	0.0000	0.1435	0.1402
Ar	0.0000	0.9496	0.9278
O_2	0.0000	17.2625	16.8660
N_2	0.6190	79.3935	77.5701
CO	0.0000	0.0033	0.0032
CO_2	5.2430	2.2476	2.1960
H_2S	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000
C_1	73.2524	0.0000	0.0000
C_2	11.9708	0.0000	0.0000
C_3	5.3198	0.0000	0.0000
i-C_4	0.8778	0.0000	0.0000
n-C_4	1.7027	0.0000	0.0000
i-C_5	0.3570	0.0000	0.0000
n-C_5	0.3802	0.0000	0.0000
C_6	0.2446	0.0000	0.0000
C_7+	0.0327	0.0000	0.0000
	100.0000	100.0000	100.0000

(b) Other Information:

Stoichiometric Coefficient "b" = 60.0770

Gross heating value of fuel gas = 45.26 MJ/m^3
= 1070 MJ/kmole

(c) NO_x Emission Factor

Using equation (2), the NO_x emission factor is given by:

$$EF = \frac{0.006698 \cdot 60.0770 \cdot 46.0055 \cdot 10^6}{100 \cdot 1070}$$

$$= 175.7 \text{ ng/J}$$

The NO_x emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled turbine engines is 126 ng/J. The value obtained here is approximately 39% higher than this EPA number.

2.2.6.5 Conclusions

The NO_x emission factor for the tested turbine engine is 175.7 ng/J.

2.3 INDIVIDUAL REPORTS FOR THE SURVEYED WASTE GAS INCINERATOR UNITS

The individual reports prepared for each of the three waste gas incinerator units surveyed are presented in the following. Since the Introduction and Procedure sections of each report are basically the same, these have been omitted from all but the first report to avoid repetition.

2.3.1 Incinerator Stacks: NO_x Test Report I-1

2.3.1.1 Summary

The incinerator stack for a small sulphur recovery unit (roughly 10 tonnes/day capacity) has been analyzed for NOx emissions. The determined rate of NO_x emissions was 0.0198 t/d* or 120.2 x 10^{-6} m^3/s**. An NO_x emission rate of this magnitude is not considered to be a noteworthy source of atmospheric pollution.

The average mass ratio of NO_x/SO_x emitted from the stack was 0.00347. Therefore, in comparison to SO_x emissions, the NO_x emissions are insignificant.

2.3.1.2 Introduction

A major application for incinerators in Alberta is the incineration of toxic tail gases from sulphur recovery units. Incinerators of this type are noteworthy sources of oxides of sulphur (SO_x) emissions. However, it is not clear whether they are also significant sources of NO_x. To determine the significance of the NO_x emissions, the results of tests conducted on the incinerator stacks from small, medium and large sulphur recovery units (i.e., in the order of 10, 100 and 1000 tonnes of sulphur per day, respectively) were examined.

This report discusses NO_x testing conducted at a small sulphur recovery unit.

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* All NO_x emissions have been expressed as an NO_2 equivalent.

** At base conditions of 21.1°C and 101.325 kPa.

2.3.1.3 Procedure

(1) The following basic data were recorded:

- date,
- location,
- test crew,
- relative humidity,
- ambient temperature,
- barometric pressure, and
- plant size.

(2) The concentration of NO_x in the stack gases was determined using the NO_x test procedure described under Method 6 in the Alberta Environment Stack Sampling Code. Six NOx samples were collected.

(3) The NO_x testing was conducted in conjunction with a regularly scheduled SO_x compliance test. This SO_x compliance test consisted of triplicate tests for determination of:

- gas velocity,
- volumetric flow rate,
- moisture content,
- gas composition (gas chromatograph analysis), and
- SO_x emissions.

Each of these tests, with the exception of that for SO_x, was conducted in accordance with the Alberta Environment Stack Sampling Code (1976).

SO_x emissions (i.e., the sum of SO_2 and SO_3 emissions) were determined using a modification of Alberta Environment (AE) Method 5 for determination of SO_2 emissions (1976). AE Method 5 requires that a distinction be made between SO_2 and SO_3 emissions. This is achieved through the use of two quantitative absorption processes - first the sample is reacted with isopropanol for preferential removal of SO_3 and then it is reacted with and aqueous H_2O_2 solution for removal of the SO_2. Since a distinction between SO_2 and SO_3 emissions is not required here, the isopropanol solution was omitted and the SO_2 and SO_3 reacted simultaneously using the H_2O_2 solution to obtain total SO_x. The result of this modification is a simplified method for determination of SO_x emissions. This modified method is accepted by Alberta Environment for use in routine compliance tests.

(4) The volumetric emission rate of NO_x at standard conditions (i.e., 101.325 kPa and 21.1°C), was determined using equation (1) below,

$$ER_V = C\ (NOx) \cdot Qs \cdot 10^{-6} \tag{1}$$

where, ER_V = volumetric rate of NOx emission, m^3/s

Qs = average volumetric flow rate of flue gases expressed at standard conditions (determined in (3)), m^3/s.

$C\ (NO_x)$ = the average concentration of NO_x (determined in (2)), ppm.

(5) The mass rate of NO_x emissions was determined using equation (2) below,

$$ER_M = 164.6 \cdot ER_V \tag{2}$$

where, ER_M = mass rate of NO_x emission, t/d.

(6) The mass ratio of NO_x to SO_x was determined using equation (3) below,

$$MR(NO_x/SO_x) = \frac{C(NO_x) \cdot M(NO_x) \cdot 10^{-4}}{C(SO_x) \cdot M(SO_x)}$$

where, $MR(NO_x/SO_x)$ = the mass ratio of NOx/SO_x.

$C(SO_x)$ = average concentration of SO_x, mole percent.

$M(SO_x)$ = molecular weight of SO_x expressed as an SO_2 equivalent (i.e., 64.059 kg/mole).

$M(NO_x)$ = molecular weight of NO_x expressed in terms of NO_2 (i.e., 46.006 kg/kmole).

2.3.1.4 Results

(1) Basic Data:

Field Work

Date: September 16, 1985
Location: North of Calgary
Test Crew: B. Reshetylo & C. Scott

Ambient Temperature: 15°C
Barometric Pressure: 661.1 mm Hg
Relative Humidity: 27%

Lab Work

Date: September 17, 1985
Location: Calgary
Ambient Temperature: 24°C
Barometric Pressure: 666.2 mm Hg

(2) Determination of NO_x Concentration

Table 93. NO_x determination - field data: NO_x test report No. I-1.

Flask Number	Time	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
2	12:05	30	2105.2	41.3	656.0	15
15	12:10	30	2027.3	38.8	661.1	15
5	13:05	30	2041.5	46.4	658.6	15
18	13:10	30	2041.2	46.4	661.1	15
12	13:55	30	2032.0	51.5	661.1	15
32	14:00	30	2004.0	46.7	661.1	15

Table 94. NO_x determination - lab data: NO_x test report No. I-1.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NOx* Concentration (ppm)
2	667.5	24	21.69
15	668.7	24	31.79
5	663.7	24	35.84
18	666.2	24	49.06
12	666.2	24	26.16
32	663.7	24	14.97

* On a wet basis.

(3) SO_x Stack Survey

Table 95. SO_x stack survey results: NO_x test report No. I-1.

Parameter	Test One	Test Two	Test Three	Average
Test Period	11:13-12:13	12:16-13:16	13:18-14:18	
Measured Average Temp. of Flue Gas at Sampling Level - °C	615	620	612	616
Measured Average Velocity of Flue Gas at Sampling Level - m/s	13.833	13.534	13.357	13.575
Calculated Average Velocity of Flue Gas at Stack Exit - m/s	13.833	13.534	13.357	13.575
Total Flue Gas Flow Rate*				
- m^3/s	4.248	4.132	4.116	4.165
- dam^3/d	367.027	357.005	355.622	359.885
Average H_2O Content of Flue Gas - mole percent	17.06	22.13	21.72	20.30
OXIDES OF SULPHUR				
Concentration - mole percent	0.5860	0.5861	0.6224	0.5982
Flow Rate* - m^3/s	0.025	0.024	0.026	0.025
Emission as SO_2 - t/d	5.712	5.556	5.878	5.716
as S - t/d	2.856	2.778	2.939	2.858
Total Reduced Sulphur - ppm, wet	N.D.	N.D.	N.D.	N.D.

N.D. - None detected.
* At 21.1°C and 101.325 kPa.

(4) NO_x ,Emissions

Table 96. Summary of NO_x emission testing: NO_x test report No. I-1.

Average NO_x Concentration (ppm)	28.87
NO_x Emission Rate	
- Volumetric* (m^3/s)	120.2×10^{-6}
- Mass (t/d)**	0.0198
NO_x/SO_2 Mass Ratio	0.00347

* At 21.1°C and 101.325 kPa
** Expressed as an NO_2 equivalent

The average NO_x concentration of 28.87 ppm shown in Table 96 was obtained by discarding the high and low sample values shown in Table 2, and taking the average of the 4 remaining samples. The volumetric and mass emission rates, 120.2×10^{-6} m^3/s and 0.0198 t/d, were then calculated using equations (1) and (2), respectively. An NO_x emission rate of this magnitude is roughly that which a 60 kW natural gas fueled reciprocating engine might produce under full load. Based on these results, the incinerator is a relatively insignificant source of NO_x emissions. Furthermore, with an NO_x/SO_2 mass ratio of 0.00347 (calculated using equation (3)), the NO_x emissions are insignificant in comparison to the SO_2 emissions.

2.3.1.5 Conclusion

The tested incinerator stack is not a noteworthy source of NO_x emissions.

2.3.2 Incinerator Stacks: NO_x- Test Report I-2

2.3.2.1 Summary

The incinerator stack for a small sulphur recovery unit (roughly 170 tonnes/day capacity) has been analyzed for NO_x emissions. The determined rate of NO_x emissions was 0.0093 t/d* or 56.4×10^{-6} m^3/s**. An NO_x emission rate of this magnitude is not considered to be a noteworthy source of atmospheric pollution.

The average mass ratio of NO_x/SO_2 emitted from the stack was 0.00189. Therefore, in comparison to SO_2 emissions, the NO_x emissions are insignificant.

2.3.2.2 Introduction

See Report I-1 (i.e., Section 2.3.1.2).

2.3.2.3 Procedure

See Report I-1 (i.e., Section 2.3.1.3).

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* All NO_x emissions have been expressed as an NO_2 equivalent.

** At base conditions of 21.1°C and 101.325 kPa.

2.3.2.4 Results

(1) Basic Data:

Field Work

Date: October 22, 1985
Location: Northwest of Edmonton
Test Crew: B. Reshetylo & D. Picard

Ambient Temperature: 5°C
Barometric Pressure: 666.5 mm Hg
Relative Humidity: 40%

Lab Work

Date: October 27, 1985
Location: Calgary
Ambient Temperature: 21°C
Barometric Pressure: 663.5 mm Hg

(2) Determination of NO_x Concentration

Table 97. NO_x determination - field data: NO_x test report No. I-2.

Flask Number	Test Number	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
17	10:38	30	2102.8	51.82	661.42	10
34	10:40	30	2003.00	59.44	658.88	10
30	10:43	30	2010.00	56.90	666.50	10
35	12:09	30	2002.00	64.52	656.34	10
3A	12:11	30	2054.30	64.52	646.18	10
32	12:18	30	2004.00	61.98	656.34	10

Table 98. NO_x determination - lab data: NO_x test report No. I-2.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NOx* Concentration (ppm)
17	676.25	21	8.03
34	673.66	21	4.78
30	668.58	21	8.23
35	671.12	21	13.24
3A	658.42	21	15.30
32	676.2	21	7.19

* On a wet basis.

(3) SO_2 Stack Survey

Table 99. SO_x stack survey results: NO_x test report No. I-2.

Parameter	Test One	Test Two	Test Three	Average
Test Period	09:12-10:12	10:22-11:22	11:30-12:30	
Measured Average Temp. of Flue Gas at Sampling Level - °C	623	627	625	625
Measured Average Velocity of Flue Gas at Sampling Level - m/s	14.660	14.924	14.187	14.590
Calculated Average Velocity of Flue Gas at Stack Exit - m/s	32.986	33.580	31.922	32.829
Total Flue Gas Flow Rate*				
- m^3/s	6.196	6.280	5.980	6.152
- dam^3/d	535.334	542.592	516.672	531.533
Average H_2O Content of Flue Gas - mole percent	20.23	20.70	20.70	20.54
OXIDES OF SULPHUR				
Concentration - mole percent	0.3364	0.3520	0.3576	0.3487
Flow Rate* - m^3/s	0.021	0.022	0.021	0.021
Emission as SO_2 - t/d	4.782	5.072	4.906	4.920
as S - t/d	2.391	2.536	2.453	2.460
Total Reduced Sulphur - ppm, wet	N.D.	N.D.	N.D.	N.D.

N.D. - None detected.

* At 21.1°C and 101.325 kPa.

(4) NOx Emissions

Table 100. Summary of NO_X emission testing: NO_X test report No. I-2.

Average NO_X Concentration (ppm)	9.17
NO_X Emission Rate	
- Volumetric* (m^3/s)	56.4×10^{-6}
- Mass (t/d)**	0.0093
NO_X/SO_2 Mass Ratio	0.00189

* At 21.1°C and 101.325 kPa

** Expressed as an NO_2 equivalent

The average NO_X concentration of 9.17 ppm, shown in Table 100, was obtained by discarding the high and low sample values shown in Table 2, and taking the average of the 95 remaining samples. The volumetric and mass emission rates, 56.4×10^{-6} m^3/s and 0.0093 t/d, were then calculated using equations (1) and (2), respectively. An NO_X emission rate of this magnitude is roughly that which a 30 kW natural gas fueled reciprocating engine might produce under full load. Based on these results, the incinerator is a relatively insignificant source of NO_X emissions. Furthermore, with an NO_X/SO_2 mass ratio of 0.00189 (calculated using equation (3)), the NO_X emissions are insignificant in comparison to the SO_2 emissions.

2.3.2.5 Conclusion

The tested incinerator stack is not a noteworthy source of NO_X emissions.

2.3.3 Incinerator Stacks: NO_x Test Report I-3

2.3.3.1 Summary

The incinerator stack for a large sulphur recovery unit (roughly 1200 tonnes/day capacity) has been analyzed for NO_x emissions. The determined rate of NO_x emissions was 0.0337 t/d* or 204.9 x 10^{-6} m^3/s**. An NO_x emission rate of this magnitude is not considered to be a noteworthy source of atmospheric pollution.

The average mass ratio of NO_x/SO_2 emitted from the stack was 0.00108. Therefore, in comparison to SO_2 emissions, the NO_x emissions are insignificant.

2.3.3.2 Introduction

See Report I-1 (i.e., Section 2.3.1.2).

2.3.3.3 Procedure

See Report I-1 (i.e., Section 2.3.1.3).

---

* All NO_x emissions have been expressed as an NO_2 equivalent.

** At base conditions of 21.1°C and 101.325 kPa.

2.3.3.4 Results

(1) Basic Data:

Field Work

Date: December 12, 1985
Location: Northwest of Edmonton
Test Crew: B. Reshetylo & T. Seedhouse

Ambient Temperature: -22°C
Barometric Pressure: 695.45 mm Hg
Relative Humidity: 98%

Lab Work

Date: December 16, 1985
Location: Calgary
Ambient Temperature: 23°C
Barometric Pressure: 703.33 mm Hg

(2) Determination of NO_x Concentration

Table 101. NO_x determination - field data: NO_x test report No. I-3.

Flask Number	Test Number	Volume (ml)		Flask Pressure (mm Hg)		Flask Temperature (°C)
		Absorbing Solution	Flask	Evacuated	Filled	
23	12:37	30	1992.7	78.23	695.45	-10
22	12:36	30	2024.7	60.45	695.45	-10
9A	13:35	30	2038.4	73.15	697.99	-10
28	13:38	30	2001.0	73.15	695.45	-10
27	14:49	30	2020.0	85.85	695.45	-10
26	14:55	30	2020.0	73.15	695.45	-10

Table 102. NO_x determination - lab data: NO_x test report No. I-3.

Flask Number	Flask Pressure (mm Hg)	Flask Temperature (°C)	Equivalent NO_x* Concentration (ppm)
23	776.99	23	3.10
22	703.33	23	7.56
9A	703.33	23	4.05
28	703.33	23	4.61
27	703.33	23	4.21
26	703.33	23	1.69

* On a wet basis.

(3) SO_2 Stack Survey

Table 103. SO_x stack survey results: NO_x test report No. I-3.

Parameter	Test One	Test Two	Test Three	Average
Test Period	11:25-12:25	12:40-13:40	13:48-14:48	
Measured Average Temp. of Flue Gas at Sampling Level - °C	400	401	403	401
Measured Average Velocity of Flue Gas at Sampling Level - m/s	13.890	13.885	13.485	13.753
Calculated Average Velocity of Flue Gas at Stack Exit - m/s	13.890	13.885	13.485	13.753
Total Flue Gas Flow Rate*				
- m^3/s	51.956	51.842	50.159	51.319
- dam^3/d	4488.998	4479.149	4333.738	4433.96
Average H_2O Content of Flue Gas - mole percent	21.21	21.78	21.34	21.44
OXIDES OF SULPHUR				
Concentration - mole percent	0.2641	0.2724	0.2568	0.2644
Flow Rate* - m^3/s	0.137	0.14[illegible]	0.129	0.136
Emission as SO_2 - t/d	31.486	32.404	29.556	31.148
as S - t/d	15.743	16.202	14.778	15.574
Total Reduced Sulphur - ppm, wet	N.D.	N.D.	N.D.	N.D.

N.D. - None detected.

* At 21.1°C and 101.325 kPa.

(4) NOx Emissions

Table 104. Summary of NOx emission testing: NO_x test report No. I-3.

Average NO_x Concentration (ppm)	3.99
NO_x Emission Rate	
- Volumetric* (m^3/s)	204.9×10^{-6}
- Mass (t/d)**	0.0337
NO_x/SO_2 Mass Ratio	0.00108

* At 21.1°C and 101.325 kPa
** Expressed as an NO_2 equivalent

The average NO_x concentration of 3.99 ppm shown in Table 104 was obtained by discarding the high and low sample values shown in Table 2, and taking the average of the 4 remaining samples. The volumetric and mass emission rates, 204.9×10^{-6} m^3/s and 0.0337 t/d, were then calculated using equations (1) and (2), respectively. An NO_x emission rate of this magnitude is roughly that which a 100 kW natural gas fueled reciprocating engine might produce under full load. Based on these results, the incinerator is a relatively insignificant source of NO_x emissions. Furthermore, with an NO_x/SO_2 mass ratio of 0.00108 (calculated using equation (3)), the NO_x emissions are insignificant in comparison to the SO_2 emissions.

2.3.3.5 Conclusion

The tested incinerator stack is not a noteworthy source of NO_x emissions.

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